INTERNAL MEDICINE

Internal Medicine

A PHYSIOLOGIC AND CLINICAL APPROACH TO DISEASE

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Preface to Second Edition

THE MANY ADVANCES of recent years in clinical and basic medical sciences are reflected in most medical texts by increased size and multiple authorship. Thus, the study of internal medicine is made to seem unnecessarily complex and formidable rather than fascinating and challenging, as it should be. The need for a more simplified and integrated approach to internal medicine prompted the original preparation of this book and now this revision. An attempt has been made to marshal the essential facts and theories and to minimize those that are unimportant and controversial.

In the few years since the previous edition of this book, the most important advances are those in which greater knowledge has been obtained of disturbed physiologic mechanisms involved in disease This knowledge has led to the development of new diagnostic techniques and has served as a tremendous stimulus to the development of new therapeutic methods.

Among the new concepts outlined in this edition are. the molecular or enzyme deficits that may be present in hereditary diseases, newer knowledge of the importance of iron metabolism in understanding various anemias, the relationship of magnesium metabolism to chronic alcoholism and other disorders, the hormone dependence of thyroid nodules and thyroid cancer, improved means of determining thyroid function, the countercurrent theory of the mechanism in concentration of urine, auto-immunity as a possible cause of disease, transplantation immunity, further understanding of factors that may induce hypertension, and the application of physiological techniques in the study of pulmonary disease

New diagnostic methods discussed include left as well as right heart catheterization, the use of radioactive cobalt in the differentiation of megaloblastic anemias, the use of radioactive diodrast* and differential sodium excretion as means of recognizing small unilateral changes in renal function, angiography as a means of studying renal disease, the

complement fixation test for syphilis, and wider use of quantitative determinations of enzymes in the blood to diagnose disease.

New therapeutic methods have permitted the further development of open-heart surgery. Because of its increasing importance, the section on congenital heart disease has been revised. Also, a summary of diagnostic points in electrocardiography has been included. Other new therapies outlined are: antihypertensive agents, diuretic agents, tranquilizers, psychic energizers, corticosteroids, growth hormone, oral antidiabetic compounds, antimicrobial agents, antimetabolites, and others. Electrolyte depletion, potentiation of digitalis toxicity, alterations of bacterial flora, psychic disturbances, alteration of immune mechanisms and other phenomena are among the undesirable effects induced by some of these drugs.

As before, I am indebted to many for help received in the preparation of this revision, particularly to Dr William Schwartz for suggestions regarding the chapters on renal disease and body fluids and electrolytes Dr Alice Ettinger, radiologist at the New England Center Hospital, provided several roentgenograms which have been included as illustrations.

ROBERT P McCOMBS

Preface to First Edition

INTERNAL MEDICINE is concerned with the detailed study of the natural history of disease, the aberrations in bodily physiology caused by disease, the means of recognizing these abnormalities, and the non-surgical methods of correcting them. Modern therapy consists in the application of physiological principles in restoring bodily function to normal or in making the best possible compromise with normal Where present knowledge is limited, empirical methods of treatment must still be utilized, but in most diseases empiricism is being supplanted by more effective methods

In teaching and in practice certain natural divisions of internal medicine have developed and some are recognized as "specialties." None of

ship results in narrow viewpoints and detrimental care of patients.

Under ideal circumstances (when there is close association between family physician, internist, radiologist, clinical laboratories, and consultants with special skills) a very high degree of diagnostic accuracy may be achieved. Even though curative therapy is available for only a relatively small portion of man's ills, it is possible through accurate diagnosis to insure that no curable disorders are overlooked, or unnecessary (and possibly harmful) therapy given; prognosis may be determined, and a firm basis established for psychotherapy.

This volume comprises a summary of the most important clinical facts, physiological concepts, diagnostic methods, and therapeutic measures of use in the study and management of internal diseases. The natural divisions of the subject are utilized in separating the material into chapters.

The "handbook" size has been retained by avoidance of duplication, elimination of detailed discussions of subjects that are primarily related to independent specialties such as neurology and psychiatry, and neglect of the subject of electrocardiography. Each of these special fields now requires a separate text for adequate presentation. Dubious theories and unproved therapeutic methods also are not included. It is hoped that this approach will permit easy reference and review.

Considerable help has been obtained directly and indirectly from fellow members of the staff of the New England Center Hospital. Special thanks are due to William Schwartz, M.D., who reviewed the chapters "Body Fluids and Electrolytes" and "Renal Disease and Renal Failure" and made many helpful suggestions. Similarly, Willard VanderLaan, M.D., and Joseph Rogers, M.D., aided in the preparation of the chapter on "Endocrinology," and Samuel H. Proger, M.D., aided in the chapter on "Disorders of the Heart." Portions of this material have been taken from my column "Clinical Notes from Medical Grand Rounds" published in the *Bulletin of Tufts-New England Medical Center.* These notes consist of opinions expressed by members of the staff during discussions at medical rounds. In some chapters factual material has been freely borrowed from an earlier work of mine, *Internal Medicine in General Practice* (Philadelphia, W B Saunders Company, 1943 and 1947), which is no longer in print.

ROBERT P. McCOMBS

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CHAPTER 1

Disorders of the Heart

PHYSIOLOGICAL CONSIDERATIONS

THE FUNCTIONAL capacity of an organ is usually related to the volume of blood passing through it in a unit of time. Thus the glomerular filtration rate is related to renal blood flow and the diffusion capacity of the lungs, at least in part, to the pulmonary blood flow. Cerebral metabolism at body temperature is determined by blood flow through carotid and vertebral arteries, cerebral functions become disturbed and various compensatory reflexes come into play whenever circulation to the brain decreases. The cardiac output normally increases in order to meet demands of the tissues for more blood.

Cardiac output. At rest and under basal conditions the cardiac output varies between 2 and 7 L. per minute and is, of course, related to the size of the individual.

The time-honored method of determining cardiac output is that outlined by Fick.

$$\text{Cardiac output (L./min.)} = \frac{\text{Oxygen consumption (ml./min.)}}{\text{A} - \text{V oxygen difference (ml./L.)}}$$

Oxygen consumption may be readily measured by having the patient breathe pure oxygen from a closed-circuit spirometer. Arterial oxygen content is determined by analysis of a blood sample taken under oil following arterial puncture. Mixed venous blood is obtained from the right atrium following cardiac catheterization. Thus if it is found that 250 ml. of oxygen are consumed per minute and that arterial oxygen content is 190 ml./L. (19 vol. %) and venous oxygen content is 140 ml./L. (14 vol. %), cardiac output is 5 L./min. Cardiac output also may be accurately estimated by measuring electronically the time of appearance and dilution in arterial blood of a known quantity of a dye (Evans blue) injected rapidly intravenously.

Under normal conditions the cardiac output depends on the venous return to the right auricle. If venous stasis is to be avoided,

coronary artery disease or cerebral vascular disease should be suspect. Unfortunately, laboratory technics are of little avail in ruling in or out coronary atherosclerosis, unless actual insufficiency exists. It may well be that refinement of present technics such as visualization of the coronary arteries, electrocardiography, the ballistocardiogram, dietary evaluation and study of the blood levels of the S_f 10 to 20 class of giant cholesterol-bearing lipoproteins may in the future produce quantitative and qualitative data.

Coronary Insufficiency

The diagnosis of coronary insufficiency is on a firmer footing. Insufficiency of the coronary circulation may be defined as that condition in which the need of the myocardium for blood is greater than can be met by the amount which is delivered. The commonest cause for this insufficiency is disease of the coronary arteries. In a small percentage of cases other factors are involved in the presence of normal coronaries. Such primary conditions which can cause secondary coronary insufficiency are *aortic valvular disease, anemia, paroxysmal tachycardia* and *hyperthyroidism.* These conditions may exaggerate pre-existing coronary disease. Thus it is apparent that pain primarily of coronary origin may be brought about by systemic as well as cardiac disorders. The search for such factors is of the utmost diagnostic and therapeutic importance. Advanced disease of the coronary arteries may be found in necropsy in persons who during life never experienced discomfort referable to the heart In a series of 476 cases in which the hearts were examined in the Department of Pathology of the Presbyterian Hospital in New York City, pain had been present in but 20 per cent of those with coronary atherosclerosis without occlusion and in 40 per cent of those with closure of a branch In such hearts there is presumably an adequate collateral coronary circulation to compensate for the affected branches.

Pain, when present, is often sufficiently characteristic to permit the diagnosis to be made from the history alone. It is usually referred to the retrosternal region sometimes a little towards the left side. Effort, emotion, eating, and cold are familiar incitants Discomfort is intense and ceases when the cause is eliminated. There may be radiation to one arm or both, or to one or both wrists or to the neck and jaw, or to an area between the scapulae alone. Instead of pain, a sense of pressure in the chest or a constriction may be felt. Other pain equivalents or "substitution symptoms" as they have been called are sudden weakness, dizziness, a short paroxysm of dyspnea, or nausea and vomiting. The sufferer frequently perspires during the attack and belches. Reference of discomfort to the epigastrium has resulted in confusing pain of cardiac origin with that due to various intra-abdominal disorders in particular disease of the gallbladder.

It is essential that the physician who is responsible for the management should discuss the symptoms in great detail with the patient. The history taken by a colleague, no matter how competent, cannot convey the same impression as that gained from a direct interview. From this personal contact is often obtained the key to the entire situation and since pain is

so frequently the only evidence of coronary disease, precise description by the sufferer must be heard to be properly analyzed for appraisal of its significance.

There may be no objective evidence of disease. The heart may be normal in size, the sounds of good quality, the blood pressure is frequently not elevated, the electrocardiogram may show no changes, yet the history is characteristic and subsequent events often quickly verify the diagnosis.

There are various conditions which may cause pain referred to the chest or arms simulating that due to coronary insufficiency. Such are:

1. *Acute serofibrinous pericarditis.*
2. Poisoning by tea, coffee, or tobacco.
3. Aneurysm of the thoracic aorta.
4. Intercostal neuralgia and pectoral myalgia.
5. Duodenal ulcer.
6. Cholelithiasis.
7. Hiatus hernia
8. Spasm of the esophagus or cardiac end of the stomach.
9. Arthritis of the spine.
10. *Psychoneurosis with symptoms referred to the heart.*

If there is a possibility that one of these affections may be responsible for the discomfort, physical examination and the appropriate laboratory tests will usually discover its presence or rule it out A cardiac neurosis sometimes presents difficulties The general demeanor of the patient, the background of emotional factors, the absence of all evidence of disease, and response to judicious psychotherapy usually serve to define the situation.

There is a small but distinct group of individuals with normal hearts who experience pain because they are sensitive to caffeine particularly when taken as coffee. The same may be true in heavy cigarette smokers. Such individuals are high-strung persons, many of them under mental or emotional strain. *The character of the pain is different from that of the anginal type. It is not severe, is of relatively long duration, and is not induced by effort or emotion. It may radiate to one or both arms causing a sensation or soreness. When present it is not aggravated by exercise. It is not relieved by nitroglycerin* Stopping the use of coffee, tea, and/or cigarettes abolishes discomfort and on occasion saves a healthy person from becoming a cardiac invalid.

Complaint of anginal pain has played a large role in claims for disability insurance. It is a simple matter for a properly instructed subject to give a convincing history of pain seizures and even to feign attacks at opportune moments The form of the electrocardiogram can be modified by taking digitalis or squill. The "racket" exposed in New York City by *the Federal District Attorney's office in 1938 showed the ease with which competent observers could be duped and large sums collected.* Dr. Robert L. Levy had the opportunity of helping the *government in preparing the* case and of testifying at the trial. It was admitted on the witness stand that coronary atherosclerosis with paroxysms of pain could occur in the absence of all objective evidence of cardiac disease. Phonograph records of

the conspirators discussing their plans were obtained over tapped telephone wires. There was a costly error on the part of the defense in stamping two sections of the same electrocardiographic tracing with different dates. The testimony of a physician and three of the alleged sufferers, who turned State's evidence, aided in convicting the culprits.

Anoxemia Test: This test furnishes an objective index of the functional efficiency of the coronary circulation. It is based on the observation that induced oxygen want produces changes in the form of the electrocardiogram which are more pronounced in patients with coronary insufficiency than in normal subjects. Specific criteria have been evolved which make possible the distinction between a positive and a negative response.

Apparatus: A tank containing a mixture of 10 per cent oxygen and 90 per cent nitrogen furnishes an unvarying concentration of oxygen in the inspired air. It does not maintain a repeatable oxygen tension in the arterial blood of all subjected. As a refinement this can be monitored by the oximeter. The gas flows through a humidifier into a rubber bag which is kept full but not distended. Two flutter valves are incorporated into the system in such a way that rebreathing is avoided. The second tank containing 100 per cent oxygen is also in the circuit so that, if desired, anoxia can be quickly relieved by turning a needle valve.

Procedure: The subject is allowed to rest quietly in bed for a period of at least thirty minutes He is told that if pain is experienced in the chest, arms, or abdomen during the test, he should at once raise his hand so that the test may be terminated. Electrocardiograms are taken with four leads; the standard leads and the precordial lead commonly designated 4F (or CF4) are used. The records are made just before the start of the test and at intervals of ten and twenty minutes thereafter. The standard period of inhalation is twenty minutes, but if pain is felt or there are signs of an undesirable reaction, an electrocardiogram is taken at once and 100 per cent oxygen is then administered for one or two minutes. If distress is severe, 100 per cent oxygen is given immediately, without waiting to take the electrocardiogram. In each lead the deviation of the RS-T segment is measured in millimeters and the direction of the T wave is noted.

Criteria of a Positive Test The result is positive when any one of the following is found: (1) The arithmetical sum of the RS-T deviations in all four leads (1, 2, 3, and 4F) is greater by 3 mm or more than in the control; (2) there is partial or complete reversal of the direction of the T wave in Lead 1, accompanied by an RS-T deviation of 1 mm. or more in this lead; (3) there is complete reversal of the direction of the T wave in Lead 4F, regardless of any associated RS-T deviation in this lead.

Precautions to be Observed: The control record should be developed and read before the test is begun in order to be certain that a recent cardiac infarct is not present. If there is doubt on this point, it is best not to proceed. In addition, the test should not be performed under the following circumstances: (1) If it has been done on the patient within the past twenty-four hours, (2) if congestive failure is present; (3) if cardiac infarction is known to have occurred within the preceding four months; (4)

during digitalis therapy or three weeks thereafter. It is known that digitalis therapy will induce a false positive test.

Results: In any large series of cases the percentage of positive tests will depend on the nature of the material studied. Instead of quoting percentages, it seems more profitable to make certain general statements which appear justified by the facts so far available.

A positive reaction may be regarded as a sign of coronary insufficiency. *A negative reaction does not exclude disease of the coronary arteries.* As is the case in any functional test, there must be a significant diminution in reserve before this can be demonstrated objectively. It cannot be too strongly emphasized that no clinical importance should be ascribed to a negative result. In Dr. Levy's experience the occurrence of pain during a test which is electrocardiographically negative is worthy of attention. If discomfort is similar in character to the original complaint, there is evidence that anoxia is capable of reproducing it. Follow-up of this group of patients has shown that a large percentage later developed unmistakable symptoms and signs of coronary artery disease. In many of them the anoxemia test subsequently became electrocardiographically positive. Thus the result of a test during which pain occurs but electrocardiographic changes are absent must be reported as negative. Patients in this category should be followed with special care and managed conservatively. In the opinion of Barnes and his associates of the Mayo Clinic, pain induced by anoxemia is of no greater diagnostic value than the patient's description of his symptoms. Others feel that the only value is that a positive test can be used as corroborative evidence of a positive history and symptomatology It should be stated that the test does not yield a quantitative expression of the degree of coronary insufficiency, nor is it possible to predict on the basis of the result, the likelihood of future coronary occlusion. It yields no information concerning the nature or extent of the pathologic lesions in the heart.

If the precautions outlined are observed, the anoxemia test is a simple, safe procedure For routine clinical purposes, the anoxemia test should be restricted to cases in which the diagnosis of coronary insufficiency is in doubt. Only a positive result is significant.

The Master "Two-Step" Test: Another test in the evaluation of coronary insufficiency is the two-step exercise test of Master and his associates This test is used in cases of doubtful nature It consists of walking an individual at a certain rate for a certain number of times up and down a two-step platform depending on his height, weight and age and taking electrocardiograms before and afterwards. The criteria for a positive test are quite similar to those of the anoxemia test. The same indications and contraindications exist as for the anoxemia test. The results must be interpreted in a similar fashion.

Other Stress Tests: Various drugs that increase the work of the heart have been recommended to quote Levine in his fifth edition of *Clinical Heart Disease*· "Finally, I have employed an Adrenalin test for angina that merits a word of explanation. It was found that the subcutaneous injection of 0 5–1 cc. of 1:1000 solution of Adrenalin reproduced attacks of angina

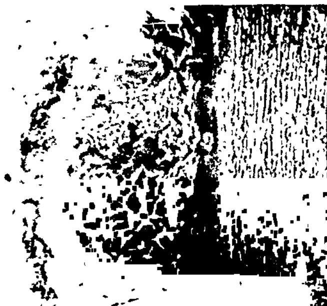
pectoris in most cases and failed to do so in control cases. In some patients even smaller doses were effective. Unfortunately Adrenalin injections are dangerous when given to patients who have heart disease and especially angina. This test, therefore, should never be employed when the diagnosis is quite definite, and the amount employed in performing the test should be small at first (e.g., 0.3 cc.), the amount being increased if necessary on subsequent examinations. When the results are positive, the patient will start complaining of the same sort of pain in the chest five to fifteen minutes after the injection is given The pain will generally be accompanied by a rise in pulse rate and in blood pressure. Just as soon as the pain is reproduced, nitroglycerin, amyl nitrite, or, if necessary, morphine is given to bring the attack to an end. I believe that the test can be helpful in some doubtful cases, particularly when it is thought that the condition is functional rather than organic. It must be borne in mind that performing any functional test for angina is dangerous, for instant fatalities have occurred."

In summary, the history and relief by nitroglycerin (although nitroglycerin will also relieve hiatus and biliary pain) are the most important points in establishing the diagnosis of coronary insufficiency. The stress tests are helpful in a few cases. Finally, conditions that may simulate coronary insufficiency must be ruled out.

Myocardial Infarction with or without Coronary Occlusion

The diagnosis of acute coronary occlusion with or without myocardial infarction has been aided by the introduction of precordial electrocardiographic leads by Wilson, and Wolferth and Wood and the more recent advent of determinations of the serum glutamic oxalacetic transaminase activity following acute myocardial infarction. Electrocardiographic interpretation and diagnostic features in myocardial infarction are adequately covered elsewhere in this text. *It must be remembered that changes in the electrocardiograms may not appear for seven to thirteen days after such an event. Hence the frequent importance of early and serial tracings.* It must be emphasized that the electrocardiogram is just another laboratory tool In many instances it will not furnish clearcut evidence for an acute transmural infarct. In such cases, the clinical picture—not the electrocardiogram—must be the determining factor in making the diagnosis. Failure to take this fact into consideration has caused many errors of commission and omission in treatment.

The original publication of LaDue, Wroblewski and Karmen in 1954 has been followed by confirmatory experimental and patient evidence that serum glutamic oxalacetic transaminase activity in suspected myocardial infarction is a great help not only in determining its occurrence but in giving a rough estimate of the size of the infarct. The test can be likened to the use of serum amylase determinations in pancreatitis with the exception that extensive liver damage also will cause an increase in the transaminase activity of the serum. Such increased activity can be differentiated from that during and after an acute myocardial infarction. The peak concentration is reached in nine to twenty-three hours after a



Aorta stained with Nile-blue sulfate and photographed with a dark-field stop The media is blue and lies to the right The intima is greatly thickened by an atheromatous plaque containing much fat, which is red, and many cholesterol crystals, which are colorless needles Magnification, 40×.



(Courtesy Eli Lilly and Company)

Cardiac coronary artery. The media is stained red The intima is greatly thickened and contains pale regions of deposition of cholesterol and nearly acellular connective tissue. Magnification, 20×

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Cardiac coronary artery. The media is stained red The intima is greatly thickened and contains pale regions of deposition of cholesterol and nearly acellular connective tissue Magnification, 20×

myocardial infarction. Tests may be done wherever a spectrophotometer is available and serum stored for from a few minutes to seven days at 0° C. Serial tests must be done. Blood should be withdrawn as soon as possible after an attack is suspected and at twelve- to twenty-four-hour periods thereafter for at least three determinations. If the test cannot be done immediately; the serum must be separated from the red blood cells. A detectable degree of hemolysis renders the sample useless.

Myocardial infarction can be diagnosed easily if the attack is typical. In its typical form the pain of coronary occlusion is very severe, is retrosternal in origin and often radiates into the jaw or the arms. Usually the pain is not relieved by nitroglycerin and it may continue for a few hours to several days. An increasing number of premonitory attacks of angina may occur. Unfortunately, the usual event is to have an attack without any clearcut warning signs. In psychotic patients pain is often not a complaint. Breathlessness, shock-like state, pallor, and drop in blood pressure may be the only signs. In nonpsychotic patients the absence of pain may occur in from 5 to 10 per cent of cases. It is not uncommon to pick up at necropsy or in routine ECG examinations definite signs of an infarction without any clinical signs or history of symptoms prior to the examination or death. Other conditions which may simulate such attacks are:

1. Pulmonary thrombosis and/or embolism.
2. Viral infections of the respiratory tract (devil's grippe).
3. Acute pericarditis.
4. Dissecting aneurysm of the thoracic aorta.
5. Gallbladder disease.
6. Perforated peptic ulcer.
7. Acute pancreatitis.
8. Acute appendicitis.
9. Acute intestinal obstruction.
10. Pneumonia.
11. Pneumothorax.
12. Spontaneous interstitial emphysema of the lungs.

It can be seen that there is a long list of diseases that may cause difficulty in the differential diagnosis of myocardial infarction. Others not already mentioned are diaphragmatic hernia, herpes zoster, arthritis of the spine, carcinoma of the lung, and syphilitic aneurysm of the aorta. The list of the diseases that may enter into a differential diagnosis is almost endless. Finally, the differentiation of simple angina pectoris and coronary occlusion needs consideration. As a rule this is not difficult since the anginal features are brief, are completely relieved by nitroglycerin, and there is usually a history of a previous attack In a few instances such attacks of angina may last longer. In people with history of a previous infarction or in which there is no change as demonstrated by the electrocardiogram and fluoroscopy, discretion is often the better part of valor. For example, one of the authors (M.W S.) has seen an alcoholic patient with known myocardial infarction develop on seven separate occasions full-blown symptoms of acute myocardial infarction with incipient delirium

tremens. In these instances the patient had to be admitted for observation to a hospital for several days before the possibility of a recent occlusion could be ruled out. In each attack the failure to develop changes in blood pressure, transaminase activity, or the electrocardiogram were of great assistance.

One of the difficult differential diagnoses may be between the symptoms due to a coronary occlusion and those of a dissecting aneurysm of the aorta. A dissecting aneurysm of the aorta may simulate an acute myocardial infarction. Chest pain and hypotension are frequent. Periodic examinations of the peripheral arterial pulses may reveal bilateral inequality or absence of a pulse. Progression of the pain caudally is very suggestive of dissecting aneurym as is the fact that many of these patients are hospitalized in a confused or comatose state. Other clues are the appearance of an aortic systolic murmur, anemia and x-ray findings pointing to aortic dilatation and rupture into pleural spaces

TREATMENT

Latent Coronary Disease: At present there is no definite treatment prophylactically or otherwise for latent undetectable coronary atherosclerosis. Individuals whose families show high incidence of coronary disease would be wise to keep their weight within recommended levels, to forego excessive smoking and eat a low-cholesterol and low-fat diet. Unfortunately there is no proof positive that this will prevent the individual from having an attack sometime in the future nor are most individuals willing to observe such a diet at the present time.

Coronary Insufficiency (Angina Pectoris): "Treatment has been defined as the art or science of amusing a sick man with frivolous speculations about his disorder, and of temporizing ingeniously, until nature either kills or cures him." There is much to be said in favor of this type of treatment in cardiovascular disease and this is one reason we should be optimistic and encouraging, so long as we protect the patient by regulating his daily routine so that he will not only do the things we wish him to do but also avoid the things we wish him not to do. This, we believe, is possible in a majority of patients without telling them they have angina pectoris. The newspapers and periodicals are so full of these diagnoses of angina pectoris and coronary thrombosis that the average individual who knows he has had one or the other expects to drop dead any minute It takes an unusually philosophical mind to live happily under such circumstances and undoubtedly some physicians are producing more suffering through such fear than coronary insufficiency itself. This is especially true in cases where such diagnosis is based on questionable electrocardiographic findings alone.

We feel that no doctor, except under unusual circumstances, should tell a patient he has angina pectoris. If a patient asks if he has angina pectoris, say, "No, you have had a temporary anoxemia of a portion of your myocardium." This statement is true and should certainly impress the patient with your vast knowledge. If you then explain that at his age he has temporarily asked his heart to do a little more than it wishes to do,

he will probably follow your advice without the constant fear of sudden death.

The late eminent psychiatrist, Dr. W. R. Houston of Austin, Texas, who had spent most of his life in China, deserves credit for the term "spasmogenic aptitude" to describe an apparently inherited prompt reaction to nervous and emotional stimuli. To quote him: "We have found ourselves forced to place it (spasmogenic aptitude) in the dim category of constitutional defects—constitutional makeup, as it is of something inborn, something taken from environment. The psychic, which means the most delicate of the mechanisms by which we make our adjustments to environment, is the best approach we have to the task of ameliorating evils that come from a spasmogenic aptitude." Coronary insufficiency, angina pectoris, and coronary occlusion are, we believe, amongst these evils. In order to treat and prevent them, every physician must become a psychiatrist. This takes time and tact. He must often readjust a patient's entire life both at home and at work.

Dr. Houston further stated that essential hypertension is virtually unknown in China; that he had never seen a case of angina pectoris in a Chinese, and if we should avoid spasm, we should be as the Chinese, "Ah yes, the Chinese lack the spasmogenic aptitude—placid, gentle, peace-loving—Buddhist—their ideal, the serene calm of Gautama Buddha, with closed lids and folded hands—symbol, the lotus flower scarcely swaying over the still pool."

The second most important form of therapy, the first being a sympathetic approach to the subject, is sedation. Most of these patients are poor sleepers and they may gain much from increased hours of sleep and relaxation.

The average patient can take 16 to 32 mg. (¼ to ½ grain) of phenobarbital, or an equivalent amount of sedatives, four times a day. Then continue as before. This usually will act as a brake upon his reactions to various physical, nervous, and emotional stimuli. His blood pressure will probably not rise quite so much and he will be more continuously relaxed. If possible, these patients should rest an hour either just after the noon meal or before the evening meal and of course the pernicious habit of a large evening meal should be avoided.

A well-known physician ate a very large supper, preparatory to catching an overnight train. Fearing that he would be late he gobbled the last few bites, bustled into his overcoat, and rushed out into a cold wintry night, only to be seized with a crushing retrosternal oppression that heralded the onset of an acute myocardial infarct. This is a perfect example of what not to do!

Patients with coronary insufficiency or the anginal syndrome can secure much relief from nitroglycerin. A low blood pressure is no contraindication to this drug as most patients with this syndrome do not develop the annoying symptoms which normal people develop, upon taking nitroglycerin Nitroglycerin should be used much more frequently than at present as a prophylactic. Many men who have previously had substernal pain on beginning an after-dinner speech, can prevent this by placing 0.3 to 0.6 mg.

(1/200 to 1/100 grain) of nitroglycerin under the tongue just before rising to speak. Others who have suffered with chest pressure and substernal pain upon walking a few blocks after a meal, can prevent this by placing 0.3 to 0 6 mg. (1/200 to 1/100 grain) of nitroglycerin under the tongue just before leaving the house.

Investigators disagree as to whether long-acting vasodilator drugs are of specific value in diminishing the number of attacks of angina pectoris. Pentaerythritol tetranitrate (Peritrate) appears to be the most effective. It may be given in doses of 10 mg. three to four times a day before meals. If this is ineffective the dose may be doubled. Its use is limited by frequent gastrointestinal symptoms. Other drugs such as the *xanthines* have been recommended but, orally, seem to have little effect with the possible exception of choline theophyllinate in doses of 200 mg. tablets four times daily. However, a trial of theophylline ethylenediamine (aminophylline) 100 to 200 mg., or theobromine sodium acetate, 500 mg., three to four times daily before meals may alleviate attacks. The beneficial results are most likely psychogenic in origin. *Heparin* treatment of patients with angina pectoris fails to influence either the clinical course or the serum lipids.

If the above measures are unsuccessful in preventing a patient with coronary insufficiency with frequent attacks of angina pectoris from becoming a total invalid, surgical procedures may be considered. The simplest of these, namely paravertebral injections of alcohol, is described in Chapter 31, and the operations of Drs. Beck and O'Shaughnessy are discussed in Chapter 23. In this edition, there is also a discussion concerning the operation of resecting the posterior roots.

Very recently, endarterectomies of the right coronary artery, the anterior descending branch, and the circumflex branch of the left coronary artery have been performed with successful re-establishment of blood flow. The ligation of the internal mammary arteries when subjected to a double blind evaluation has been shown to produce little if any improvement. The operations of Drs. Beck and O'Shaughnessy have not been tested in similar fashion.

Since H. L. Blumgart and his associates first reported in *Circulation* in 1950 the use of radioactive iodine in the treatment of thyroid patients with angina pectoris, over a thousand carefully selected patients have been treated. Dr. Blumgart himself is the first to point out that only about 5 per cent of patients with angina pectoris will benefit from such a procedure. These patients are benefitted in about 75 to 85 per cent of cases. They are usually those in whom the disease seemed to be stationary over long periods of time with frequent incapacitating attacks of angina. Several small doses of radioactive iodine are usually given. The patient will have a temporary thyroiditis and slight exacerbation of their symptoms. Symptomatic relief occurs as the blood cholesterol rises and the basal metabolic rate decreases. Careful follow-up and study of these patients has not revealed as yet any deleterious effects from such treatment.

Other measures that may be tried consist of long-term anticoagulant therapy to prevent thrombosis and a high-protein, low-fat diet to prevent

further atherosclerosis. Certainly, it has been well proven that coronary disease is much more prevalent in those eating a high-fat diet and who are overweight. Whether reduction and a low-fat, low-cholesterol diet will cause regression of symptoms and atherosclerosis is yet to be proven in any individual patient. Reduction of weight should be encouraged and if the patient is willing to consume such a diet over a long period of time there is no contraindication. The role of anticoagulants in the prevention or alleviation of coronary atherosclerosis is yet to be proven.

In all patients with angina pectoris the psychotherapeutic aspects should be explored carefully and tactfully. The frequency and severity of attacks can be reduced markedly when the patient can learn to resolve his anxieties by facing and solving promptly the daily problems, be they large or small. The physician can reassure the patient by quoting the hopeful prognostic aspects (see Prognosis).

Acute Myocardial Infarction: The most important forms of treatment in acute myocardial infarction are relief from pain, rest, and reassurance. The relief of pain is accomplished through the administration of 10 to 16 mg. (1/6 to 1/4 grain) of morphine sulfate intravenously or hypodermically. If the patient is not relieved within thirty minutes, 16 mg. (¼ grain) doses should be repeated at hourly intervals. Atropine sulfate 0.4 to 0.6 mg. (1/150 to 1/100 grain) should be given with each hypodermic injection. If the patient is not entirely relieved by the above medication within a few hours, 0.5 Gm. (7½ grains) of aminophylline can be given intravenously over a five to ten minute period of 60 mg. (1 grain) of papaverine hydrochloride intramuscularly with caution. To obtain rest, the patient should be allowed to assume the most comfortable position and to turn from one side to the other under most circumstances. From the very beginning, the patient should be reassured. The physician should not show his apprehension nor permit the nurses and family to show apprehension, even though the situation seems critical, as fear probably accentuates myocardial irritability through the effect of epinephrine, thus increasing the possibility of ventricular fibrillation with sudden death.

The patient should be on a liquid diet high in carbohydrates, certainly during the febrile period. Small feedings seem more advisable at first as semisolid and then solid food is introduced. Unless there is considerable distention, an enema or laxative is not necessary in the first twenty-four to forty-eight hours. Then it is our belief that an alkaline laxative is preferable to an enema, since it presumably cleanses the entire intestinal tract, whereas an enema may not. If the patient is apprehensive and restless, he should be given sedation. It is our custom to use 30 mg. (½ grain) of phenobarbital four times a day, unless the blood pressure is too low.

If there is any breathlessness or cyanosis, oxygen is indicated, either by use of the oxygen tent, especially in the summer time, or through the use of the B.L.B. oxygen mask. If the patient is apprehensive or uncomfortable while in the tent, of course he should not be made to remain in it. The oxygen tent with maximum flows will produce an atmosphere of 35 to 50 per cent oxygen. The mask will produce 100 per cent oxygen. Prolonged usage of oxygen concentrations over 70 per cent are not advisable

as bronchial irritation, bronchopneumonia, and pulmonary edema occur. Intermittent periods of two to four hours with rest periods of an hour are safe. Nasal tubes should be avoided if possible; if they are used, they should be cleaned every four to six hours and removed daily. Water used to humidify the oxygen must be guarded against contamination by hospital personnel to prevent adding respiratory infection as a complication.

If there is evidence of congestive failure or if the patient develops auricular fibrillation with an apical rate above 100, digitalization is indicated. We realize that some reports have been made suggesting that digitalis, following acute myocardial infarction, increases the possibility of embolic phenomena and also decreases the clotting time. We feel, however, as in other cases in which digitalis is indicated, that it should be used when treating these patients in spite of the above possibilities. Actually, the present feeling is that digitalis, *per se*, has no effect upon coagulation and that any changes following digitalis administration are secondary to changes in body fluids.

Many cardiologists believe that a patient should be given 200 to 400 mg. (3 to 6 grains) of quinidine sulfate four times a day in all cases of acute myocardial infarction. Others give it only in the presence of premature contractions. Of course, the object is to lessen myocardial irritability and the chance of development of ventricular fibrillation.

The use of anticoagulants in the treatment of acute myocardial infarction has aroused a great deal of interest. Preliminary reports suggesting a reduction in thromboembolic phenomena from approximately 35 to 5 per cent have been confirmed by a large-scale study conducted by the American Heart Association under the supervision of Dr. I. S. Wright. This study was made simultaneously in many hospitals throughout the country by giving Dicumarol orally to alternate patients with acute myocardial infarction

Some studies of autopsy series revealed thromboembolic lesions in over 40 per cent of patients with myocardial infarction as opposed to 15 per cent in patients dying with chronic diseases in the same age groups. Pulmonary infarcts arise mainly from three causes—local pulmonary thrombosis, right heart thrombi, and peripheral veins. It is felt that leg and pelvic veins constitute the most important cause of pulmonary infarct. Arterial thromboses usually arise from the left atrium and ventricle. These accidents start soon after the onset of the disease, and the incidence reaches a peak in the second week. As we do not know which patients will benefit by therapy, treatment should be started as soon as possible. Both heparin and Dicumarol are potentially dangerous drugs and treatment should be instituted only under strict supervision in the hospital with a laboratory that furnishes accurate prothrombin times

In skilled hands there are no absolute contraindications to the use of anticoagulants. In the presence of blood dyscrasias with increased tendency to bleed, renal insufficiency, ulcerative lesions, hepatic dysfunction, and subacute bacterial endocarditis, the drugs should be used with utmost caution, if at all. In some of these conditions the clotting or prothrombin time may indicate that no drug is needed.

The two drugs that have been studied extensively are heparin and Dicumarol. Heparin does not require laboratory facilities but is expensive. It is given most effectively by vein at four- to six-hour intervals. Its presence affects prothrombin values and, consequently, prothrombin determinations should be delayed for at least three hours after the last dose. Because its effect intravenously lasts only three hours, it is relatively safe. Different preparations vary in potency. Dicumarol is inexpensive and given orally. Its action is delayed, the full effect occurring about forty-eight hours following ingestion. This makes dosage schedules difficult. The aim is to maintain a constant prothrombin time somewhere between 20 and 30 per cent of normal. The ideal level may be closer to 20 per cent. The exact mechanism is unknown at present. To repeat, it can only be given safely if prothrombin times are determined daily by an accurate laboratory.

Current treatment schedules are as follows: If it is felt that there is no emergency and treatment is started within several days of onset, Dicumarol is given alone. On the first day 300 mg. are given by mouth and an initial prothrombin time is determined; 200 mg. are given on each subsequent day that the prothrombin time is above 30 per cent of normal. However, there will be wide individual variations, and each case must be handled on its own merits. Prothrombin times must be taken at least daily for the first few weeks. At present, four weeks of treatment are advised. Heparin is best given intravenously in 50 mg. doses (undiluted—5 cc.) every four hours. Heparin can also be given intramuscularly in 75 to 100 mg. doses. The dose at bedtime may be increased to 125 to 200 mg. safely, thus permitting eight hours of uninterrupted repose through omission of one dose Heparin can be given, as mentioned previously, when laboratory facilities are not available and also when it is felt that treatment is on an emergency basis. Finally, the two drugs are combined when treatment is started late or if thromboembolic phenomena have already occurred In this case, heparin is discontinued after the prothrombin time is less than 30 per cent, bearing in mind that prothrombin time cannot be determined from blood drawn less than three hours after the injection of heparin.

The main complication of anticoagulant therapy is hemorrhage. Minimal hemorrhagic manifestations occur in about 2 per cent of cases as evidenced by hematuria, localized ecchymosis, and epistaxis. If the prothrombin level is about 20 per cent of normal, Dicumarol treatment need not be discontinued. Major hemorrhage occurs in about 1 per cent of cases and treatment should be stopped temporarily. If bleeding is continued or alarming, vitamin K_1 is recommended in doses of 30 to 72 mg. intravenously and fresh blood by transfusion to replace the lost blood. Treatment should be resumed cautiously when the prothrombin level is again between 20 and 30 per cent of normal. Hemorrhage due to heparin medication is controlled by withdrawing the drug, the clotting time returning to normal in three hours. In alarming cases, protamine, given intravenously, will bring the clotting time to normal almost instantly. From 50 to 100 mg. of protamine will nullify the effect of 50 mg. of heparin

At the present time we cannot be dogmatic about the use of anticoagulants. We wonder whether the high percentage of embolic complications claimed for the "control" patients may not be due partially to such factors as keeping the patient practically motionless in bed and using bedpans. The former promotes peripheral stasis of the blood while the straining produced by the latter easily could release any thrombi formed. It is difficult to ignore the opinions of many cardiologists who feel like Dr. W. Evans of England. He studied 2,351 patients treated with anticoagulants against 4,451 controls. In addition he compared his own series of 1,000 consecutive cases treated without anticoagulants. This series had a mortality rate lower than the treated patients of ten different investigators. Evans could find no significant differences between the larger series, although in 57 per cent of the treated patients the diagnosis was "false." His conclusion is worth quoting in defense of those physicians who withhold anticoagulants. "*That anticoagulant treatment in coronary occlusion will go the way of other discarded remedies is certain. Let it go soon. Let it go now, before remorse weighs too heavily on those who may continue for a little time longer to advocate its use.*"

Numerous articles have warned against the perils of prolonged bed rest in patients with congestive heart failure and urged that the patient with acute myocardial infarction be allowed out of bed earlier than has been previously customary, because of the possibility of phlebitis with a pulmonary infarction However, we feel that the average patient with acute myocardial infarction should not be allowed out of bed before four to six weeks have passed, in order to insure the development of as adequate a collateral circulation as possible, with the exception that in most cases it is safe to allow the patient to use a commode which causes much less strain on the circulation than using the bedpan. Occasional gentle flexing of the muscles, turning from side to side, bed baths with alcohol rubs, and occasional deep breathing should lessen the incidence of complications. At the end of four to six weeks, the patient should be allowed to sit in a chair for half an hour, increasing the time out of bed an hour a day.

During the latter part of convalescence, a careful evaluation of the past daily routine of the patient and the contemplated future course should be made. The impression left with the patient by the doctor at this point is all important. We feel that the average patient can return to a sedentary occupation in two to three months. Although it is debatable, because of the possibility of further occlusion, we believe that it is safe to allow these individuals to drive a car three months or so after their acute episode. Also, if they do not have angina of effort, three or four months after their original attack any mild form of exercise, such as golf, swimming in warm water, etc., seems indicated, if desired.

Nitroglycerine, Peritrate, and choline theophyllinate may be used to prevent and treat substernal pain brought on by effort. Dosage schedules are given in the section concerning treatment of coronary insufficiency.

Although we have no proof that tobacco produces vascular pathologic changes, it is believed generally that tobacco constricts blood vessels, hence patients with angina of effort or a healed myocardial infarct should

not smoke. Fortunately alcohol dilates vessels and therefore it is perfectly safe for such individuals to drink alcoholic beverages in moderation.

PROGNOSIS

Many recently published long-term reports reveal that the prognosis for patients with angina pectoris and proved myocardial infarction is by no means as dark and gloomy as we thought formerly. Richards, Bland, and White, in a twenty-five-year follow-up study of 456 patients with angina pectoris, found that the average survival of the group was almost ten years. The six who are still living have survived an average of 31.7 years. Twenty-four per cent died from non-cardiac causes. The 24 per cent who had normal findings at the first examination lived longer than the others. By comparing this mortality rate to the mortality rates for healthy people, these authors found that angina pectoris increased the annual mortality rate for males by 7 per cent and 5.3 per cent for females.

In a similar twenty-five-year study of patients with myocardial infarction, Dr. Richards and his associates found that 19 per cent died within the first four weeks (mostly within the first week). Of those who survived this "immediate death" period, 50 per cent were alive five years later, 33 per cent at ten years, 14 per cent at fifteen years, and 5 per cent at twenty years. In the table following this paragraph, much better survival figures are indicated for those who made a "complete recovery" than for those patients who were limited by angina or dyspnea. These figures do not mean, however, that the ECG or heart size returned to normal in the "complete recovery" group. The survival rate for this group is very impressive. The average age at onset for the whole series was 56.7 years, and 84 per cent were males.

Survival (Years)		5	10	15	20	25
"Complete recovery"	(34%)	82%	56%	29%	13%	11%
Limited by angina	(39%)	40%	30%	11%	2%	
Limited by dyspnea . .	(27%)	20%	0%			
Total 162 patients		49%	31%	14%	5%	4%

Dr. Weiss and his son found in a five-year follow-up of men who had a myocardial infarction that 431 returned to some form of gainful employment *in an average time of three months* after their first infarction. Many patients returned to work despite symptoms of coronary insufficiency or heart failure. Within five years, 67 per cent were still employed, 22 per cent had died, and 11 per cent had retired. There were few "unskilled" laborers and 80 per cent were below the age of sixty years. None of the patients in this report who had a myocardial infarction or who developed heart failure claimed it was due to their work and hence compensable.

In another report by Master and Dack (1940) it was found that 53 per cent of 415 individuals who had a myocardial infarction returned to work. The number of subsequent attacks of myocardial infarction, the develop-

ment of congestive heart failure, and the number who subsequently died were no greater in the working group than in those who did not return to work.

From these reports and from many others, it is evident that patients with coronary insufficiency and healed myocardial infarction have a good chance of living for many years. It is our feeling that such patients should be encouraged to return to as normal a life as possible.

Although many of these patients who go back to work will be able to carry on only through the frequent use of nitroglycerin in the presence of retrosternal pain, still there is no indication that their deaths will be hastened. The opposite is much more likely. The satisfaction of earning money and serving a useful purpose in the community should make a patient much more comfortable than to sit fearfully and unfruitfully for years awaiting the grim reaper.

We are not sure why the average physician believes that a person with angina pectoris or a myocardial infarct is incapacitated for life. Perhaps he tells the family this since he fears that the patient, upon returning to work, may suffer further injury or die from another myocardial infarct, and that he will be held responsible for this, since he allowed the patient to return to work. Even in many so-called laboring jobs, Hellerstein and Ford have found that oxygen consumption is only two or three times the resting levels except for very short periods of time.

As far as physical activity is concerned, there is less clinical coronary insufficiency and thromboses among those who engage in more than average exercise during their lifetime than those in sedentary occupations. Actual sleep, hypotensive crises, and other events that cause diminution in coronary flow would seem to be more provocative of acute infarction than exercise. Those who die suddenly during violent exercise often are found at postmortem examination to have had their thrombosis earlier.

All too often the heart heals but the patient remains an invalid because of anxiety. Personality studies will help the physician to determine whether the patient is a person who accepts dependency and thinks in terms of retirement, and who will become an invalid, perhaps subsisting on insurance benefits, or whether he will fight against dependency. The earliest return to work should be urged to prevent the patient from falling out of the routine or habit of work. This is the wicked part of this compensation business. Little attention is directed toward determining the functional capacity of the heart, which is the real criterion of the degree of incapacity. Doctors fear what may happen and forbid a return to work. Individuals are rated as 50 to 75 per cent incapacitated, when they have only become unaccustomed to work. Actually those who are not given financial compensation and are forced to work live longer!

The only limitation that might be imposed is the type of work such patients should do. In this respect, over half the patients with coronary insufficiency in a small series followed by Dr. Harold Feil of Cleveland died a sudden death presumably associated with ventricular fibrillation or sudden cardiac standstill. Obviously, such individuals are not good candidates for piloting planes or passenger trains. Perhaps they should

not be encouraged to drive automobiles. With these few exceptions, the patient's capacity for work will depend upon his physical and mental response. The experience in Highland View Hospital devoted to chronic disease where many patients with evidence or history of old myocardial infarcts are returned to self care following strokes, hip fractures, etc., has been highly gratifying. Very, very rarely has the cardiac disorder slowed or prevented attempts to get the patients back on their feet and walking.

SELECTED REFERENCES

Etiology and Prevention

Katz, L. N: The Role of Diet and Hormones in the Prevention of Myocardial Infarction, Ann Int. Med 43 930 (Nov) 1955
Keys, A, and Brock: Cholesterol, Diet, and Coronary Disease, Lancet 2 1103, 1955
Moritz, A R: Trauma, Stress and Coronary Thrombosis, J A M A 156.1306 (Dec. 4) 1954
Moschcowitz, E: The Pathogenesis of Arteriosclerosis, Am. J Cardiol 1:295 (March) 1958
Pierce, F T, and Gufman, J W Lipoproteins, Liver Disease and Atherosclerosis, Circulation 4:25 (July) 1951

Diagnosis

Baer, S: Varied Manifestations of Dissecting Aneurysm of the Aorta, J A M A 161:689 (June 23) 1956
Isaacs, J, Wilburne, M, and Gunther, L: Ultra Low Frequency Acceleration (Force) Ballistocardiogram in Myocardial Infarction, Am. J Cardiol. 1:323 (March) 1958
LaDue, J. S: Serum Glutamic Oxaloacetic Transaminase, Lactic Dehydrogenase, and Glutamic Pyruvic Transaminase Activity in Evaluation of Heart Muscle Damage, Am. J Cardiol 1 308 (March) 1958
Levine, Samuel A. Clinical Heart Disease 5th ed Philadelphia, W B. Saunders Company, 1958
Marchand, W. E. Occurrence of Painless Myocardial Infarction in Psychotic Patients, New England J. Med 253 51 (July 14) 1955
Master, A M, Jaffe, H L, and Pordy, L Cardiac and Non-Cardiac Chest Pain: A Statistical Study of "Diagnostic Criteria," Ann Int. Med 41 315 (Aug) 1954
Master, A M: Graphic and Laboratory Diagnosis in Coronary Disease, J A M A 165:1771 (Dec 7) 1957
Nuzum, F R: Relationship of Esophageal Hiatus Hernia to Angina Pectoris, J.A.M A 148:1174 (April 5) 1952
Stroud, W D, and Wagner, J A: Silent or Atypical Coronary Occlusion, Ann Int. Med 15.25 (July) 1942

Treatment

Bl [illegible]

Bc [illegible]

Capeci, N E, and Levy, R L Anticoagulant Therapy in Cardiac Infarction, (cited by Levy, R. L. J Chron Dis 4 339, 1955)
Dickson, L C, Jr: A Philosophy of the Management of Coronary Occlusion, Postgrad. Med, p 3 (July) 1958.
Ellis, L B, and Hancock, E W: Current Status of Therapy in Coronary Artery Disease, J.A M A 163.445 (Feb 9) 1957
Evans, W: Anticoagulant Therapy in Coronary Occlusion, Proc Roy Soc Med 47:318, 1954
Levine, S A, and Lown, B: "Armchair" Treatment of Acute Coronary Thrombosis, J A.M A 148 1365 (April 19) 1952
Plotz, M Improved Response in Angina Pectoris to a New Drug Combination, Postgrad Med, p. 189 (Aug) 1958

Schluchman, M.: The Failure of Anticoagulant Therapy to Prevent Myocardial Infarction in Patients with Premonitory Symptoms of an Impending Coronary Occlusion, Ann Int Med 46 728 (April) 1957.

Selzer, A, and Rytand, D. A Use of Drugs in Shock Accompanying Myocardial Infarction, J A M.A 168.762 (Oct 11) 1958.

Prognosis

Benton, J. G, and Rusk, H A: The Relation of Physical Activity and Occupation to Coronary Artery Heart Disease, Ann Int Med. 41 910 (Nov) 1954

Hellerstein, H. K., and Ford, A B· Rehabilitation of Cardiac Patient, J A M A 164·225 (May 18) 1957

Kaufman, J G, and Becker, M C Rehabilitation of the Patient with Coronary Artery Disease, Ann Int Med 41.9 (July) 1954

Levine, S: Pitfalls in Interpreting Coronary Artery Statistics, Am Heart J. 58:639 (Nov.) 1958

Master, A M. *et al* · Survival and Rehabilitation after Coronary Occlusion, J.A M A. 156 1552 (Dec 25) 1954

Richards, D W, Bland, E F, and White, P D· A Completed 25-year Follow-up Study of 200 Patients with Myocardial Infarction, J Chron Dis 4:415 (Oct) 1956

Richards, D W, Bland, E F, and White, P D A Completed 25-year Follow-up Study of 456 Patients with Angina Pectoris, J Chron Dis 4 423 (Oct) 1956.

Robb, G P, and Marks, H H What Happens to Men Disabled by Heart Disease? Read at the Sixty-second Annual Meeting of the Association of Life Insurance Medical Directors of America, October 14-16, 1953.

Sigler, L. H Prognosis of Angina Pectoris and Coronary Occlusion, J A M A 146.998 (July 14) 1951.

Stroud, W D· Patients with Healed Myocardial Infarction Should Work, Geriatrics 10·184 (April) 1955.

Weiss, M M, Sr, and Weiss, M M, Jr· Five-Year Follow-up Study of Men Who Returned to Work after a Myocardial Infarction, J A M A 168 17 (Sept. 6) 1958

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30B

Use of Anticoagulants in Treatment of Thromboembolic Disease

Means are now available by which the physician can control to a significant degree the clinical course of thromboembolic conditions and achieve a gratifying reduction in morbidity and mortality. This ability to modify and control the course of aberrant clotting inside the body is due in large measure to the development of potent anticoagulant drugs.

Jay McLean, while working in Howell's laboratory, in 1916 described the anticoagulant activity of a cephalin fraction of heart and liver extract. When by 1935 this substance was sufficiently purified to be clinically usable as heparin, definitive prophylaxis and treatment of intravascular thrombosis became feasible. Best and Murray of Toronto and Jorpes and Craaford, in Stockholm, soon reported their success with the new agent. One of the present authors (I.S.W.) treated the first patient with heparin in the United States in 1938. Shortly thereafter, Karl Paul Link and his co-workers, searching for the agent in spoiled sweet clover which caused hemorrhagic sweet clover disease in cattle, discovered and purified Dicumarol and thus provided a longer-acting anticoagulant which could be administered orally. By 1941, Butt, Allen and Bohlman; Meyer, Bingham and Pohle; and Prandoni and Wright had reported on the clinical use of the new agent. The following decade saw the development of an extensive experience in the treatment of acute myocardial infarction, as well as thrombophlebitis. More recently, workers have gone on to explore the concepts of prophylaxis, the "thrombotic state," and the application of long-term coverage to selected high-risk groups including patients with cerebral thrombosis and those with embolism.

To maintain a proper perspective the reader should remember that these drugs have only been available for slightly over twenty years Some of the conditions for which anticoagulants promise to be of greatest help have been under investigation for less than a decade. It is the aim of this chapter to provide a summary of the information and opinions available at this time.

PATHOLOGIC PHYSIOLOGY OF THROMBOSIS

Three primary considerations must be borne in mind when considering the pathogenesis of thrombosis:

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1. Blood is a constantly varying mixture of many components, some of which undoubtedly have not been recognized as yet. In any thrombosing process in vivo, most, if not all, of these components become involved and many of them play a dynamic role in the formation of the thrombus.

2. In disease states the development of thromboembolic phenomena does not proceed in the orderly fashion suggested by any of the schematic outlines which have been developed for academic or symbolic purposes. All schematic presentations must of necessity be oversimplified; the whole process is enormously complex. Actually, at the same instant many stages of the process may be taking place—chemical, physical, physiologic and pathologic.

3. The clotting tendency, as measured by clotting time or prothrombin activity from blood drawn from one set of veins, may bear little relationship to the clotting tendency in some other area of the vascular tree in which, for example, tissues may be undergoing serious changes as a result of trauma, infection or cancer. There should be no great surprise, therefore, when a patient has a hemorrhage in one area while he has a thrombosis elsewhere, or when thrombosis or hemorrhage occasionally occur while a patient is considered to be at the optimal level of anticoagulant therapy as measured by the usual tests of blood drawn from the antecubital veins

The development of an arterial thrombus usually depends on: (1) changes in the wall of the artery which roughen the intima or narrow the lumen, such as with atherosclerosis or thromboangiitis obliterans; (2) changes in physical and chemical constituents which lead to the deposition or concentration of fibrin in the local area, and (3) adhesion of cellular and other particles to the wall, which then build up to narrow or block totally the lumen of the vessel. Inflammatory reactions, such as are encountered in thromboangiitis obliterans, periarteritis nodosa and local infections, produce irregular surfaces which also encourage thromboses Trauma, whether accidental or surgical, may roughen the intima with the same result. These latter conditions are so rare as etiologic factors that they will not be further considered in this chapter.

The next steps leading to thrombosis are extremely complex and far from fully understood. We are not certain whether or not the primary action may be physical rather than chemical. For example, it has been suggested that the inner surfaces of the tubes (arteries) may normally have negative (repulsive) charges which tend to keep the components of the blood from adhering to them The natural anticoagulants, as exemplified by heparin, appear to have fairly strong negative charges. These may aid in keeping certain molecules, notably those of fibrinogen, in a state of mutual repulsion. When conditions change, reducing these negative charges, it becomes easier for the long, slender, rotating molecules of fibrinogen to adhere to each other, producing the sticky fibrin which in turn may adhere to the injured wall of the vessel. This enmeshes other components of the blood, first platelets, which in turn contribute to this reaction by the release of thromboplastin which speeds up the production of more fibrin. Sheppard and others working in our laboratory have

explored this field for some years, but much more needs to be done to clarify the physical aspects of this process.

More has been done by countless workers on the biochemical aspects of the coagulation process. Unfortunately, most of this work, of necessity, had to be carried out in vitro under conditions which are foreign—although probably somewhat parallel—to those encountered within the walls of the vascular system. The following is a modification of several theories which have been evolved:

Contact with the negatively charged surface of the vessel wall initiates blood coagulation by a disintegration of platelets with release of platelet lipid factor, thromboplastic Factor III, which reacts with Factor VIII (antihemophilic A), Factor IX (antihemophilic B), Factor IV (calcium), and Factor III (thromboplastins). Factor V (pro-accelerin) and Factor VII (proconvertin) act with these substances to produce convertin which initiates a minimal conversion of Factor II (prothrombin) to thrombin. This speeds up the accelerator system which activates the conversion of prothrombin to thrombin. When thrombin is formed in sufficient concentration, it slows up the long, narrow, rodlike fibrinogen molecules which rotate on both axes and these molecules mesh together to form the sticky mat of fibrin. Other newly discovered factors, such as the Stuart-Prower and Hageman Factors, doubtless play roles in the early stages of clotting.

Balanced against these interactions which move in the direction of coagulation is a series of inhibitor reactions which tend to inactivate or lower the concentration of Factor III (thromboplastin), Factor VII (proconvertin), convertin, accelerin, Factor IX (antihemophilic B), prothrombinase and thrombin. The action of the anticoagulant drugs in support of this inhibition, thus interfering with coagulation and thrombosing, will be outlined later.

The reactions described may appear to be complicated, but they represent a rather crude oversimplification of what actually takes place. Many new factors have been described in the literature—some of them may prove to be of importance, but where they fit into the picture is as yet not determined.

The morphologic development of the clot, which might be considered to be the end-result of the processes discussed, was described in detail many years ago. The importance of platelets was recognized in 1882, but their mechanism of function and adhesive characteristics have more recently been elaborated by Apitz, M. B. and H Zucker, and H. P. Wright. It now seems clear that the surfaces of platelets are not entirely dependent on their surrounding medium, but under certain conditions, such as those encountered postoperatively or with marked infection, the products of platelet activity probably escape through the surface of the platelets and the cell-plasma interface becomes covered with a film of fibrin. This adhesive surface contact film has such viscosity that even though two adherent particles may have a like electric charge, their mutual repulsion may not suffice to overcome the cementing action of the viscous film In addition, the hydrophilic colloids which are increased in the blood postoperatively act by reducing the surface charges on the cells and by modifying the

positions of the absorbed water on the cell surfaces. The cells are then enabled to approach each other more closely, and, because their electrokinetic potentials are reduced, their surface tension is sufficiently great to overcome their mutual repulsion so that aggregation may take place. Fibrinogen and globulin are potent hydrophilic colloids in this regard and their increase during postoperative periods may be partially responsible for the increase in platelet adhesiveness. Sludging due to slowing of the blood flow through narrowed channels makes coagulation easier.

Little-understood etiologic factors are known to encourage the coagulation tendency. These include the following: cancer of any tissues, but especially cancer of the pancreas and lungs; polycythemia vera; familial thrombosing tendency; and individual idiopathic thrombosing tendencies. Once the coagulation process is started the thrombus propagates from its fixed adherent head, the body later adhering to the wall of the vessel, often becoming almost a portion of it. A fresh thrombus usually has a loose floating tail which grows and represents a source of potential danger as an embolus. It may also cause complications by propagating proximally and adhering to the walls of the vessel, thus blocking off additional branches and interfering further with the circulation.

ANTICOAGULANT DRUGS

Heparin: Heparin is a complex mucoitin polysaccharide with a molecular weight of approximately 16,000. The molecule is a long chain of repeating units containing hexuronic acid and acetylated glycose amine, and contains sulfate ester groups which produce a high negative charge. In fact, heparin is the most powerful organic acid existing in the body. The material is stored in the mast cells in the connective tissue near the capillaries and surrounding blood vessels. Normal blood usually contains small amounts of heparin, and the level has been estimated at 0.009 mg. per 100 milliliters. One or more heparin cofactors are present in the blood, and for some of the more significant in vivo effects, the cofactor must be present. There is a lag of several minutes between the injection of heparin and the appearance of measurable anticoagulant activity, and it is believed that this period is required for the interaction with the cofactor.

Commercial material is prepared from the lungs of cattle and pigs. It is available as an aqueous solution of the sodium salt of heparin, and is standardized by comparison with an international reference solution. One International Unit is roughly equivalent to 1/130 mg., and for practical purposes, one mg. may be considered as 100 International Units. The usual pharmacologic preparations contain 1000 units (10 mg.) per milliliter for intravenous use More concentrated preparations have been developed for intramuscular and subcutaneous use, and some have attained concentrations as high as 20,000 units (200 mg.) per milliliter. Although various repository menstrua have been developed, some containing gelatins or vasoconstrictors to slow the release of the material, these have been largely superseded by the more concentrated aqueous preparations. Heparin is only effective when given parenterally, and no anticoagulant effect can be obtained by oral or sublingual administration.

The mode of action of heparin is such that it is often referred to as an "end-stage anticoagulant." It enters directly into the clotting mechanism in three ways: (1) *Antithromboplastic:* Heparin blocks the effect of thromboplastin, and delays the conversion of prothrombin to thrombin. A cofactor is necessary for this effect. (2) *Antithrombic:* The effect of thrombin in polymerizing the fibrinogen molecules into thrombin is also blocked by heparin, acting with a plasma cofactor. The high negative charge on the heparin molecule may be one of the factors producing this effect. (3) *Platelets:* Heparin has also been shown to reduce platelet adhesiveness. It reduces the production of serotonin. Heparin also has an antilipemic effect, but this is not anticoagulant.

As a pharmacologic agent, heparin has definite characteristics. Whether they be considered advantages or disadvantages depends largely on the effects which are desired and upon the relative importance of theoretical or practical considerations. The drug is rapid in onset, and fairly uniform in the response from individual to individual. It is not cumulatively toxic when given over long periods of time. Should overdosage occur, its consequences will quickly subside by virtue of the brief period of effect of a given dose. The same brief period of action, however, becomes a severe disadvantage when repeated doses over long periods of time are required, and the absence of any oral means of administration poses severe practical problems. Furthermore, the drug is expensive—a day's dosage will usually cost between $5.00 and $10.00. Similarly, although the direct action of heparin is helpful when powerful and immediate effects are necessary, it makes the likelihood of bleeding more significant. In postoperative patients in whom anticoagulation is required, bleeding has occurred following the administration of heparin. Patients with cerebral vascular occlusions seem to have a tendency to bleed following heparin therapy.

Administration: Heparin is effective only if given parenterally. Following an intravenous dose of approximately 1 mg./kg., there will be a lag of several minutes, and then a rapid rise, until the clotting time is five or six times that of the control. There will then be a gradual return to normal levels within three or four hours. One way of maintaining heparin effect, then, is to give intravenous doses of between 50 and 100 mg. every three or four hours, with the aim of keeping the clotting time at its lowest, at least twice the control values. Clotting times are measured by the Lee-White method before each dose, and the dosage is regulated by adjusting the amount of the dose, or the interval between doses. Wessler has developed an indwelling plastic catheter capped by a rubber diaphragm through which repeated injections can be given directly into the vein Intravenous administration can also be accomplished by dissolving 200 mg. of heparin in 1000 ml. of normal saline solution or 5 per cent glucose solution, and administering this at a rate of 15 to 20 drops per minute. with occasional checks on the clotting time

The more concentrated aqueous solutions now offer an alternative method to the repeated venipunctures or constant infusion by the above technics. If 100 or 200 mg of concentrated aqueous heparin is administered by the deep subcutaneous route, effective anticoagulation may be main-

tained for a period of eight to ten hours. Therefore, once the immediate effect has been obtained by the first intravenous injection, subsequent injections may be spaced as widely apart as every eight hours. It is advisable to check the clotting time at least once daily, and to delay subsequent doses when the clotting time exceeds twice the control level.

The Scandinavians have had an extensive experience in the use of intravenous heparin. They generally give four doses, divided throughout the day, of about 100 mg. each. They do not check the clotting time, and report few hemorrhagic complications. In this country, however, it is common practice to observe clotting times at intervals when the drug is being administered

Heparin has no toxic effects except those of overdosage, which will produce bleeding. Rare instances of alopecia have been reported, but in twenty years of continuous experience with heparin, we have never seen such a case. If the drug has been given intravenously, its effect is sufficiently short-lived so that reversal is seldom necessary. If desired, or if longer-acting routes of administration have been used, protamine sulfate is an effective antidote. It is given slowly, intravenously, on a milligram-for-milligram basis, and has an immediate effect. Transfusions of fresh whole blood will also effectively counteract heparin in vivo.

No substitute for heparin has as yet been developed. Treburon, Paritol, dextran, phosphorylated hesperidin and other preparations have been tried, but have been found unsatisfactory for this use in human beings.

The Coumarin Compounds: The coumarins are relatively simple chemical compounds which exert a profound effect on the clotting mechanisms of the blood. They have no effect upon shed blood, but act upon the liver to inhibit the production of prothrombin and Factor VII. They may also affect Factor IX, the Stuart-Prower Factor, and others less well-defined at this time. Their action is accomplished through a biologic antagonism with vitamin K No other effect of Dicumarol upon the body has ever been demonstrated, and other tests of liver function show no change when massive doses are given.

Dicumarol is given by mouth. The usual initial dose is 300 mg. on the first day, 150 to 200 mg. on the second day, and thereafter 50 to 100 mg. for a daily maintenance dose. By the third day, the therapeutic level will usually have been maintained. Many patients can be well stabilized on 75 mg. a day. Day-to-day dosage is regulated by one of the standard tests for the Quick one-stage prothrombin time The therapeutic range varies from laboratory to laboratory, depending on the technic and on the thromboplastin reagent which is used. The general aim is to keep the prothrombin time between one and a half and two times the control level, giving prothrombin concentrations or activity approximately equivalent to between 10 per cent and 30 per cent. If the prothrombin time in seconds is higher than the desired upper limit, then no Dicumarol is given until it reaches the mid-point or lower in the therapeutic range. If it falls below the desired therapeutic level, additional Dicumarol above the daily maintenance dose is given. There is usually a thirty-six- to seventy-two-hour lag between the administration of additional drug and the response in the

prothrombin time. A practical method of ordering Dicumarol or other coumarin derivatives for a hospital patient is to write as follows: "Give —— mg. of Dicumarol daily unless the prothrombin time exceeds 35 seconds (with a control of 15 seconds ±1)." In this way the nurse does not give an overdosage and the physician as well as the patient is protected from this occurring accidentally by lack of changing an order. If the time is excessively high, it can be counteracted by giving one of the vitamin K_1 preparations.

Long-Term Administration: It is usually preferable to hospitalize patients during the first ten days to two weeks of anticoagulant therapy, until an approximation of the daily dosage requirements can be established. When the patient is to be discharged from the hospital, an estimate of the daily requirement of the coumarin drugs may be obtained by averaging the doses for several preceding hospital days. It is advisable to reduce this by about 25 per cent, as a safety factor during the transition from hospital to office supervision. The prothrombin time is then checked three to seven times the first week, twice the second week, and thereafter once each week or two weeks The periodic checks should be no less frequent than every two weeks as unexpected fluctuations in dosage response may occur after years of regular response. It is advisable for the patient to have several tablets of vitamin K_1 available so that in the event of hemorrhage he may be advised by his physician to take the drug at once, instead of waiting to arrive at the hospital In practice, it has worked well to have the patient come to the hospital, clinic or office in the morning, have the blood drawn and be seen by the attending physician. The determination of prothrombin time is made during the morning, so that at the end of the morning, the physician has the data and prescribes the daily dosage for the next week or two. In the afternoon the patient either telephones or returns to the clinic and is given the dosage schedule. Dosage schedules should be planned in order to distribute an appropriate amount of the drug over the entire one- or two-week period, and changes in dosage should be gradual rather than abrupt.

Laboratory Control: For guidance in dosage, the physician is almost completely dependent upon the laboratory. None of the commonly used clotting time tests, simple enough to be done on large numbers of patients in a clinical setting, can be expected to give an accurate picture of the many changes in the clotting mechanism which are produced by anticoagulant drugs. The aim, therefore, is to select a test which will give an adequate index of coagulability so that the physician may estimate an appropriate dosage. Although many tests for the measurement of the activity of coumarin drugs have been suggested, none has stood the test of clinical use as well as the Quick one-stage prothrombin time, or its modifications. Inasmuch as the results are a function of the thromboplastin used, there is no absolute range which may be delineated as therapeutic. The American Heart Association's study of the use of coumarin drugs for the treatment of myocardial infarction, as well as other studies, suggests that if the patient's prothrombin time is maintained between one and a half and two times the control, then adequate protec-

tion is afforded, with little risk of hemorrhage. The conversion of these data into hypothetical percentages adds another step, with more possibilities for error of misinterpretation, and it is therefore recommended that the original data in seconds be preserved. Owren and others have found the so-called "P-P" test of prothrombin and proconvertin to be another useful guide to dosage.

Choice of Drug: As stated earlier, Dicumarol is the basic prothrombinopenic drug, and a tremendous experience in its use has been accumulated. It is nontoxic, inexpensive, and stable. Its absorption, however, from the gastrointestinal tract is slow and unpredictable, and it requires several days for the therapeutic effect to be well established.

TABLE 1

COMMON HYPOPROTHROMBINEMIC DRUGS: THEIR ACTIONS AND THEIR DOSAGE

Name of Drug	*Average Initial Dosage (in mg) on Successive Days*	*Daily Maintenance Dosage (in mg)*	*Duration of Action in Days*
Dicumarol	300, 200, 100	50 to 100	2 to 4
Tromexan	1500	300 to 900	1 to 2
Hedulin	250	50 to 100	1 to 3
Liquamar	15, 9	3 to 6	up to 7
Warfarin Sodium	40 to 60	5 to 10	3 to 6

Table 1 lists the drugs which are now most widely used, together with their dosage levels. We believe that most practitioners should be familiar with the use of Dicumarol, and some one of the newer drugs. It has been our experience that both Liquamar and Warfarin Sodium have much to offer. Liquamar is extremely steady from week to week, once the appropriate dosage has been established. Warfarin Sodium is also easy to use and has the advantage that it can be administered intravenously or intramuscularly as well as by mouth.

CONTRAINDICATIONS TO ANTICOAGULANT THERAPY

Anticoagulant drugs are contraindicated in those situations in which the possibility of hemorrhage already exists, and when bleeding, if it were to occur, would be disastrous. Absolute contraindication exists in bleeding ulcerated lesions of the gastrointestinal tract, severe hepatic or renal insufficiency, and immediately after operations on the brain and spinal cord. Blood dyscrasias with hemorrhagic features, subacute bacterial endocarditis, and dissecting aneurysm of the aorta are also strict contraindications Numerous other situations are encountered which may be considered "relative contraindications." These include mild hepatic or renal insufficiency, moderately elevated blood pressure, polycythemia vera, anorrhexia nervosa, and pregnancy which is very close to term. In these situations, the clinician must weigh the relative risks of the thromboembolic disease from which the patient is suffering against the risk of hemorrhage.

Hemorrhage: The principal complication of all anticoagulant therapy is bleeding. There can be no question that continued anticoagulant therapy will result in a slight increase in the amount of undesired bleeding. However, as clinicians have become more skilled in the use of these agents, and laboratories have become more widely proficient in the performance of the tests, progressively less and less hemorrhage has been reported.

An important change in recent years has occurred in the attitude of physicians toward hemorrhage. It was once considered catastrophic, regardless of the nature or extent of the bleeding, requiring immediate and permanent cessation of all future anticoagulants. The modern approach, however, is to regard hemorrhage as an unfortunate and undesirable complication for which adequate control is usually available, and which does not automatically cut off all hope of further anticoagulant therapy. Although the majority of the bleeding will take place when prothrombin times are elevated and prothrombin content is lowered in excess of the therapeutic range, an occasional patient will be found to bleed at the times usually thought of as therapeutic. When the bleeding has been controlled, and the patient is again placed on anticoagulants (as may be necessary in some of the severe "clotters") within the therapeutic range, bleeding usually will not recur. When seemingly unwarranted bleeding is observed, particularly in the gastrointestinal or genitourinary tracts, it should be regarded in the same light as though no anticoagulant had been administered. Careful study in a number of such cases has revealed an otherwise unrecognized, asymptomatic and still operable carcinoma or ulcer. Urinary bleeding is frequently associated with calculi or polyps in the bladder.

Vitamin K Antagonism: A true physiologic antidote to the coumarin drugs exists in the vitamin K preparations. The most effective and satisfactory is vitamin K_1, known commercially as Mephyton or Konakion. The drug may be administered by mouth or intravenously, and will exert measurable effect within four hours. In the event of severe hemorrhage, as in extreme over-dosage of a coumarin drug, 50 to 100 mg. of vitamin K_1 should be given at once, and may be repeated in four to eight hours. Further dosage is rarely necessary. If dosages of this magnitude are given, it will be impossible to obtain a response to coumarin therapy for several days, and large doses should be given only in extreme emergencies. In the more usual situation, where the prothrombin time has become excessively high on a particular day, a dose of 5 or 10 mg. of vitamin K_1 by mouth will usually bring the patient into the therapeutic range. If there has been excessive blood loss, or if even more immediate restoration of blood prothrombin levels is required, fresh whole blood should be given.

THROMBOPHLEBITIS

Prior to anticoagulants, approximately 20 per cent of all patients with deep thrombophlebitis died from pulmonary embolism. Early detection and prompt anticoagulant treatment have reduced this mortality to less than 2 per cent, and the remaining fatalities usually occur in patients in whom the embolus occurred before adequate therapeutic effect had been

tion is afforded, with little risk of hemorrhage. The conversion of these data into hypothetical percentages adds another step, with more possibilities for error of misinterpretation, and it is therefore recommended that the original data in seconds be preserved. Owren and others have found the so-called "P-P" test of prothrombin and proconvertin to be another useful guide to dosage.

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cardial infarction from one-third to two-thirds that of untreated subjects. These results have been so widely accepted that it now becomes difficult to find significant numbers of untreated patients for controls or for other studies. The general effect, as measured in percentage reduction of mortality, has been consistent throughout these series, which now include thousands of cases.

Thromboembolic Complications: In addition to the over-all reduction in mortality, the case protocols and autopsy material have provided additional evidence of a notable reduction in nonfatal thromboembolic complications. Where almost two-thirds of the controls were found to have mural thrombi at postmortem, they were found in only one-third of the treated subjects. Extracardiac thromboembolism was diagnosed clinically in 17 per cent of controls and 10 per cent in treated patients. When autopsied material was examined, even more striking findings were observed, with 44 per cent thromboembolic complications found in the control-subjects as against 23 per cent in those receiving anticoagulants. In only 13 per cent of all patients with thromboses had the diagnosis been made clinically. When multiple emboli were taken into account, the studies showed that forty-two cases of such complications were found in each 100 untreated patients; only thirteen cases were found per 100 treated patients. The full import of these figures is emphasized by the crippling nature of nonfatal emboli which may involve the brain or periphery, and result in stroke or necessitate amputation.

Selection of Patients: On the basis of these results, it is felt that all patients in whom the diagnosis of acute myocardial infarction is made should receive immediate treatment with anticoagulants, unless some specific contraindication exists. Attempts have been made to define "good-risk" patients who will not need anticoagulants, but these attempts have not been successful. Although the criteria are good for defining those patients in whom thromboses are inordinately likely to occur, they err by overlooking a significant number of presumed "good-risk" patients who later develop further thromboses or emboli. In several series it has been necessary to reclassify as high as 25 per cent of the patients within the first forty-eight hours, and most authorities now feel that, in the absence of specific contraindications, all patients should receive anticoagulant therapy. At the International Conference on Thrombosis and Embolism in Basle in 1954, the question of "good-risk" classification was discussed by a panel of eleven authorities. It was the unanimous opinion that no criteria are reliable. It was agreed that all patients, in whom the diagnosis of myocardial infarction has been made, should receive anticoagulant therapy unless specific contraindication exists. This position was unanimously reconfirmed by a panel of authorities on this subject held during the International Congress of Hematology in Rome in 1958.

Risk of Hemorrhage: According to recent reports, the risk of bleeding due to anticoagulants would seem to be from 2 to 3 per cent, with fatality occurring in about 0.5 per cent of the patients. It should be borne in mind that hemorrhage is a complication occurring in persons having myocardial infarction without anticoagulant therapy. In the American Heart

Association series, the percentage of hemorrhage found at postmortem was 6 per cent in the controls and 15 per cent in the treated patients coming to autopsy. In the majority of these subjects it was an incidental finding and did not contribute to the death of the patient.

Long-Term Maintenance of Anticoagulation Therapy: Several groups have now reported on long-term maintenance of patients on anticoagulants following one or more myocardial infarctions. Suzman, Ruskin and Goldberg reported a series of 208 patients, all of whom had a myocardial infarction and had received six weeks of anticoagulant treatment for the acute attack. One hundred seventy-one were followed for from three to seventy-six months, and it was found that the over-all mortality rate was reduced from 33 per cent in the control patients who discontinued their treatment after the first six weeks to 7.3 per cent in the treated group on continuous long-term therapy. It appeared, in this series, that the greatest benefit was obtained by patients who had been seriously ill or had had several previous infarctions In this group, anticoagulants reduced the mortality rate from 47 to 9 per cent. The group of patients having milder cases, corresponding in general to the "good-risk" classification, did sufficiently well so that anticoagulants did not offer much additional protection. Keyes and Smith, in Detroit, have studied another large group. They found that patients, who had had one myocardial infarction and were maintained on long-term anticoagulant therapy, had a four-year mortality rate of 8 per cent as opposed to 41 per cent in the controls. If there had been two or more infarctions, the mortality rate became 12 per cent in treated patients and 63 per cent in controls. An elaborate clinical trial was conducted in Norway by Bjerkelund. He studied 277 patients who were divided into well-matched control and treated groups. After six weeks of initial treatment for the acute infarction, both control and treated groups were followed for a period of up to three years The results were highly significant statistically, and showed that the risk of recurrence in patients receiving anticoagulants was reduced to three-fifths of that of the controls. The mortality rate was reduced to 50 per cent of that of the control group, and in the autopsied material, thromboembolic phenomena were three times as frequent in the control as in the treated group. Further breakdown of these statistics showed that, in this group, the benefit was highly significant in patients under sixty years of age. While the treated group showed a definite improvement, the difference was not statistically significant at the 5 per cent level in patients over this age Furthermore, most of the benefit was demonstrated during the first year of treatment. Studies in our clinic and those of Owren demonstrate, however, that discontinuance of long-term therapy is followed by an increased incidence in thromboembolic complications so that much of the gain achieved during the first year is lost. The experiences of the New York Hospital group, as well as the cooperative study conducted by Nichol and the large experience by Owren of Oslo, also show considerable reductions in thromboembolic complications and mortality rate during long-term treatment.

In summary, numerous groups have shown that by the administration of anticoagulants one can achieve a reduction in the mortality rate during

one to five years following myocardial infarction and that the incidence of both recurrent myocardial infarctions and thromboembolic complications elsewhere in the body can be significantly reduced. It appears that the greatest benefit is obtained in patients under the age of 60, in those who have had recurrent infarctions or other thrombotic complications, and also those whose initial attack has been severe. Results of several studies are shown in Table 2.

TABLE 2
EFFECT OF LONG-TERM ANTICOAGULANT THERAPY ON MYOCARDIAL INFARCTION

	Number of Cases		*Mortality (in per cent)*		*Recurrences (in per cent)*	
Author	*Control*	*Treated*	*Control*	*Treated*	*Control*	*Treated*
Bjerkelund	118	119	5 7	2 2	12 9	6 2
Keyes	234	121	15.	3 3	38 0	2 0
Manchester	200	204	43.	7 8	34 0	14 0
Nichol	1,091	417	37 4	12	.	
Owren	1,613	131	12	5 9		
Suzman	88	82	33	7 3	27 3	8 5
Ensor	268	140*	23 1	35 7*		
Average or Total	3,612	1,214	28%	11%		

* "Pseudo controls": Those patients who had received anticoagulants for briefer periods

Impending Infarction: Papp and Smith have introduced the concept of "impending myocardial infarction" to describe a state in which angina becomes progressively more persistent and severe. They feel that, in a number of such patients, actual infarction has been averted by immediate and vigorous anticoagulation therapy. It may be assumed that any acute increase in the angina has (by induction) a 50 per cent chance of being associated with the laying down of thrombus, and would therefore be an excellent indication for anticoagulant intervention The merits of this course of action are difficult to document with clear-cut statistical evidence, and it has been our feeling that better justification for the initiation of anticoagulant therapy may be derived from the general context of the atherosclerosis-anticoagulant interaction which has been described above. It has therefore been our practice to recommend anticoagulants when any acute increase in angina occurs, in the absence of contraindications, on an empirical basis. It is always explained to the patient that it is on a trial basis. Many patients report improvement, but since angina is a purely subjective phenomenon we have found this hard to evaluate. Owren (1955) has reported that long-term anticoagulant therapy reduces the mortality rate in patients with angina by 50 per cent.

In certain instances, a myocardial infarction will be suspected, but diagnosis will be delayed until laboratory studies or serial electrocardiograms have been completed. Patients such as these should be started on anti-

coagulant therapy quickly, and maintained at therapeutic levels until the diagnosis is established or discarded. Mural thrombi, in particular, form during the early days following infarction, and can be suppressed with anticoagulants. If it is decided that infarction has not occurred, the hypoprothrombinemia will clear in several days following the discontinuance of the coumarin drug.

RHEUMATIC HEART DISEASE

In 4 to 8 per cent of patients with chronic rheumatic heart disease, emboli are recognized clinically. The combination of atrial fibrillation and mitral stenosis provides a dilated atrium and a site for blood stasis which is particularly dangerous in regard to emboli formation. Between 25 and 50 per cent of patients with this hemodynamic configuration are found to have atrial thrombi, and about half of such patients can be expected to develop emboli in the natural course of their disease if untreated.

In Cosgriff's clinic, twenty-eight patients were followed, and, during 275 months before Dicumarol therapy, 103 embolisms were recorded. During 625 patient-months on treatment, thirteen emboli were observed and four of these occurred during the first six weeks of therapy. At the time of his report, 71 per cent of patients in whom treatment had been terminated had had another embolism. Askey has collected ninety-eight cases from five series, including the above. In a total of 1944 patient-months without treatment there were 276 emboli; 2995 months of anticoagulant therapy yielded thirty-five such accidents. The over-all reduction in this group of patients, then, is from one embolus every seven months to one every seven years!

Mitral valvuloplasty offers another method of treating the patient with mitral stenosis. In some clinics, peripheral embolization is an indication for surgery. Following successful surgery, a sharp reduction in the frequency of emboli is observed. Good criteria for the relative merits of surgery and long-term anticoagulant therapy are not yet available, but certain facts have already emerged. First, any patient with rheumatic heart disease who has had one arterial embolism is in grave danger of subsequent emboli. These will occur in over half of such patients, usually within six months following the first embolus. These patients should, therefore, be placed on anticoagulant therapy at once. Secondly, they should be maintained on this treatment indefinitely, unless surgery is decided upon. Thirdly, and perhaps most important, the immediate postoperative period is one of the most hazardous in the entire life of the patient with rheumatic heart disease. As high as 15 per cent of these patients have experienced thromboembolic complications during the first weeks after surgery. For this reason, we consider it imperative that all patients be started on anticoagulant therapy after surgery and be maintained on this therapy for six weeks. After that period the decision to stop the treatment must be dependent on the thromboembolic history and experience of the particular patient.

Anticoagulant therapy should be continued indefinitely in patients with multivalvular lesions not suitable for surgery, and in patients in whom

pulmonary emboli arise from the right side of the heart. This last group has been found to have continued emboli after surgery. The group of patients who had sustained repeated peripheral and pulmonary emboli prior to the institution of anticoagulation, and who have subsequently been free of any thromboembolic events, represents one of the earlier demonstrations of the dramatic and frequently lifesaving potentialities of long-term anticoagulation.

CEREBRAL VASCULAR DISEASE

Usually occlusive cerebral vascular disease is either caused by emboli or by atherosclerosis with thrombotic complications. The first group results largely from systemic emboli in rheumatic heart disease, and the discussion in that section of the chapter applies to cerebral as well as systemic disease. There is no area of the body with less recuperative power than the brain, nor any in which the consequences of certain small areas of infarction can be more crippling. Specific syndrome complexes have been described, and, of these, intermittent insufficiency of the vertebral basilar artery system and of the carotid system appears to present lesions which respond well to anticoagulant treatment. In many instances the repeated bouts, which otherwise result in death or paralysis in 50 per cent of the patients, have been completely terminated. In patients with complete occlusion of these two vessels, treatment is also advisable unless too extensive a neurologic deficit has been sustained.

In the New York Hospital series, 100 patients with cerebral vascular thrombosis or embolism have been followed for a total of 5133 patient-months. During 2842 patient-months without anticoagulant therapy, there were 229 thromboembolic events of which sixty-seven were cerebral. The same patients were maintained on long-term ambulatory anticoagulation for a total of 2291 patient-months, and during this time experienced seventy-two thromboemboli of which sixteen were cerebral. There were a total of three patients with fatal cerebral hemorrhages. In addition to the striking reduction in cerebral and other thromboembolic occlusions, there was a reduction in episodes of "insufficiency" in those patients with recurrent focal cerebral ischemia while under adequate anticoagulation.

Therapy: The evidence suggests that any patient with intermittent insufficiency of the vertebral or basilar artery or the carotid system should receive prompt anticoagulant therapy Such treatment should also be used in patients having thrombosis or embolism of any intracranial artery or vein if there is reasonable evidence that hemorrhage is not an important factor. The limits of this chapter preclude discussion of the typical symptom complexes, and the reader is referred to the publications of Millikan and Seikert, Fisher, and Denny-Brown for a more complete discussion of the intermittent premonitory episodes and transient visual and neurologic defects which are seen in these syndromes

We consider the lumbar puncture to be a necessary procedure in the evaluation for therapy, and will forego the examination of the spinal fluid only because of specific contraindication. The recent interest in the use of anticoagulants has necessitated lumbar punctures in large numbers of

patients with a variety of diagnoses and it has been found that if the tap is performed gently, with a small-gauge needle, and if only a small amount of liquid is removed, the risk is small indeed. The assurance that no blood was present in the spinal fluid will, in the presence of normal blood pressure, weigh heavily against any significant element of hemorrhage It is not, however, absolute proof against bleeding within the brain tissue.

The above focuses on the use of anticoagulants for the treatment of cerebral disease per se. For more detailed consideration, the reader is referred to the reports of Fisher, Millikan and Siekert, and those of McDevitt, Foley and Wright from our Vascular Service.

ARTERIOSCLEROSIS OBLITERANS

Since arteriosclerosis obliterans of the peripheral arteries is usually a nonfatal, slowly progressive disease, with long plateaus, and occasional favorable response to existing therapy, few reports have appeared on long-term studies

Castro and Stritzler reported on a group which included twenty-one patients with arteriosclerosis treated with anticoagulants and felt that they had observed significant improvement in most of them. They noted the healing of ulcers, rise in skin temperatures, and relief from ischemic pain There were no controls. In the group of cardiac patients studied by Bjerkelund, it was noted incidentally that eight of the controls developed intermittent claudication and that this was noted in only one of the treated cases. In examining limbs which have been amputated following arteriosclerotic gangrene, one is struck by the frequency with which fresh thrombi are encountered. In a study of legs amputated following arteriosclerotic gangrene, fresh thrombotic occlusions were found in 50 per cent of the subjects. Many of the older occlusions are also thrombotic in nature, and the entire pathologic picture would suggest that the maintenance of anticoagulant therapy, while not influencing the basic pathologic substrate of intimal proliferation, might reduce the frequency and extent of thrombotic occlusion, and thus preserve the rich anatomic collateral circulation of the legs. Inasmuch as arteriosclerosis obliterans is slow in its progress, it is not usually considered an indication for anticoagulant therapy, but further studies are required to give reliable figures for controls and treated patients.

ROLE OF ANTICOAGULANTS IN ATHEROSCLEROTIC CARDIOVASCULAR DISEASE

Despite the large volume of work which is being done on the etiology and treatment of occlusive vascular disease due to arteriosclerosis, we have as yet no definitive preventive or cure. In selected areas, long-term anticoagulant therapy has been found to reduce the thromboembolic complications which play a major role in disability and death from this disease

The role of thrombosis in producing vascular occlusion has been exhaustively studied in the coronary arteries. In the autopsied material from the American Heart Association study, approximately 75 per cent of the acute coronary occlusions were thrombotic. Bjerkelund has reviewed fifteen series, totaling 2736 cases of coronary occlusion. In the total series, 46

per cent were found to be due to thrombosis. The care with which pathologic studies were performed in some of these series was not clear. Bjerkelund points out that the effect of anticoagulants should be most beneficial in preventing recurrent thromboses. Zollinger and Papacharalampous have demonstrated central growth of occlusive thrombi, which could cause occlusion of more proximal branches. This provides a morphologic basis for the clinically observed phenomenon where extension of a presumably stabilized thrombus occurs. Wright, Marple and Beck reported such extension in forty of 442 controls, as compared with nineteen of 589 treated patients

Wessler's observation that 50 per cent of limbs amputated following arterial insufficiency contained fresh occlusions has already been mentioned. Estimates of the percentage of occlusions due to thrombus in a cerebral disease are extremely variable, ranging from 40 to 90 per cent, and are a function, among other things, of how diligent a search is made. Merritt has reviewed the material from The Neurological Institute in New York, and feels that 50 per cent of the occlusions are due to thrombosis.

Duguid, Harrison and other workers have revived Rokitansky's "thrombosis theory," and suggest that deposition of fibrin may represent a primary rather than secondary factor in the development of some vascular occlusion. If this approach is followed, anticoagulation may represent a direct approach to the cause of arteriosclerosis. At present, however, more emphasis is placed on the concept of preventing complications, rather than averting the cause

In view of the many observations which indicate the importance of thrombosis in vascular occlusion due to arteriosclerosis, it has seemed reasonable to offer long-term, or "permanent," anticoagulation as an effective mode of therapy in the management of patients with arteriosclerotic vascular disease. It should be remembered, first, that the function of this therapy is to lessen the thromboembolic complications of a disease of unknown cause, and not to prevent or cure the basic disease; second, that no better treatment is as yet available; and, finally, that once thrombosis and subsequent infarction have occurred, little can be done to restore life to tissues which are no longer viable. It is the aim of this therapy to *prevent* the development of further thrombotic occlusion

Anticoagulants represent a dynamic and positive approach to one of medicine's most difficult problems. The evaluation of this kind of treatment requires that the physician deal with the conceptual entities of statistical risk, rather than the easily perceived realities of electrocardiograms and x-rays. In appropriate situations, however, the ability of anticoagulation to prevent disease is as striking as is the ability of highly-regarded therapies to cure other diseases

By virtue of the extreme variability from patient to patient, the long-term nature of the illness, and the impracticality of the "double blind" type of experiment, many of the results of anticoagulant therapy can not be proved in the fashion of Koch's postulates. However, the disease has an overt thrombotic element; the drugs are known to affect thrombosis; and the general direction of all observations has been to indicate significant benefit from long-term treatment

In general terms, it may be said, then, that in addition to specific disease entities, such as acute myocardial infarction and the cerebral vascular insufficiency syndromes, there is good indication for the continued use of anticoagulants in any patient who has had two clinically recognizable occlusions caused by arteriosclerosis, at least one of which is in the cerebral or coronary circulation. The evidence is becoming increasingly strong that this rule should be extended to those who have suffered a single attack, if maximum protection is desired.

SURGERY

The application of anticoagulant therapy in the treatment of postoperative thrombophlebitis has been well established. In an attempt to forestall the development of postoperative thrombosis, certain situations have been delineated in which this risk is inordinately high. These include operations on the female pelvic organs, operations of long duration or great magnitude, extensive tissue damage, widespread carcinoma, old age, malnutrition, and a history of previous thromboembolism. In these situations, unless there is some specific contraindication, it is advisable to begin anticoagulants one or two days after surgery, and to continue them until the patient is fully ambulated. In most cases the surgery can even be performed with the prothrombin time at about twenty to twenty-three seconds with a control of fifteen seconds. In this fashion, the incidence of postoperative thrombophlebitis can be sharply reduced.

A significantly high percentage of patients, who undergo cardiac surgery, develop thromboembolism. As high as 50 per cent of patients with mitral stenosis have intracardiac thrombi, which may be dislodged by the valvular surgery per se; furthermore, the raw edges of the fractured valve and the suture site in the atrial wall are known nidi for thrombus formation. We believe that all patients who are to undergo mitral commissurotomy should have four to six weeks of treatment with anticoagulants after surgery. The postoperative treatment should be begun within forty-eight hours of the operation. Miscall, of Cornell, has conducted a controlled study in which fifty-two patients underwent commissurotomy without any anticoagulants, while sixty comparable patients received anticoagulants before and after surgery. About half of the latter had the surgery performed while active anticoagulation was maintained. Postoperative emboli were observed in fourteen of the controls, and in two of the anticoagulated patients; the risk of embolization had been reduced from 27 per cent in the controls, to 3 per cent in the protected group. When the procedure was done under the effect of the anticoagulant, about 10 per cent had significant bleeding in the postoperative period. This concept was developed in large measure by Sturm and Astrup of Copenhagen. They have clearly shown the feasibility of carrying on major surgery *during* anticoagulant treatment. One report describes major procedures, such as bowel and lung resections and cardiac surgery, and in eighty such procedures the operative blood loss was little more than in controls. Although such procedures are not as yet widely adopted in this country, the possibility should be kept in mind for selected subjects in whom the risk of thromboembolism

is deemed to be excessively high. In open-heart surgery involving an extracorporeal circulation, anticoagulation with heparin is used routinely, and without question.

DENTISTRY

The problem of extractions and other oral surgery will of necessity arise when a group of older patients are maintained on anticoagulants for long periods of time. In several patients who had been uneventfully maintained in the hypoprothrombinemic state for long periods of time, the cessation of coumarin therapy for dental work resulted in crippling or fatal thromboembolic complications. We have, therefore, maintained anticoagulants during dentistry. If the prothrombin time is kept at the lower end of the optimal therapeutic range or allowed to fall only slightly below this level, extractions can be performed with no additional risk. Whatever bleeding does occur will respond well to topical thrombin and gelfoam. Although numerous reports in the literature report hemorrhage following extractions, the hemorrhages have uniformly occurred when the prothrombin time was excessively high. In our experience no serious hemorrhage has occurred with prothrombin times of between eighteen and twenty-eight seconds.

OPHTHALMOLOGY

Application of anticoagulant therapy to the eye centers largely upon occlusion of the retinal artery, and thrombosis of the retinal vein. Arterial closure may be thrombotic or embolic; in either event by the time the patient is evaluated for anticoagulation, it is too late to reverse any changes which have occurred in the retinal tissues The occlusion should, therefore, be considered in terms of the rest of the body, rather than in hopes of restoring circulation to the eye In retinal vein thromboses, on the other hand, considerable benefit may be obtained from anticoagulation, both in terms of controlling the local thrombosis, and preventing the development of secondary glaucoma To prevent this late complication of retinal vein thrombosis, anticoagulation should be maintained for at least four months.

OBSTETRICS AND GYNECOLOGY

The remarks made about general surgery apply particularly to pelvic surgery. If the patient has been in lithotomy position for a long period of time, the stirrup rests may further predispose to thrombophlebitis.

Postpartum Thrombophlebitis: In pregnancy, an additional element must be taken into consideration. It has been shown by Alexander and others that a so-called hypercoagulable state exists during pregnancy. These workers have shown that at least one element is the rise in Factor VII (proconvertin) during pregnancy. In addition to the change in the blood coagulability, the mechanics of pregnancy are such that, during and after term, large varicosities may be present with stasis of the hypercoagulable blood. The continued frequency of postpartum thrombophlebitis therefore is not surprising

Deep thrombophlebitis should be treated as a medical emergency in the same fashion as any other deep thrombophlebitis Superficial thrombophlebitis should also be treated as a serious complication of pregnancy. When the cords are large and the thromboses are evident beneath the skin, therapy with the coumarins is indicated. Usually this will involve at least one week of treatment in the hospital and two more weeks of therapy after discharge, on an ambulatory basis. Since coumarins may be transmitted in the mother's milk, the infant should not be nursed. Obstetricians will customarily administer estrogens to dry up the breasts in non-nursing mothers, and at the conclusion of this course of estrogens, vaginal bleeding may occur. This bleeding is usually about the magnitude of a normal menstrual period. It is important to remember that this is not a sign of excessive hypoprothrombinemia. In cases of doubtful or extremely localized areas of thrombophlebitis, on occasions we have withheld the anticoagulants for twenty-four hours during which time local warm packs were applied. *If at the end of that time there was still evidence of local activity,* we have advised the use of anticoagulants. This prolongation of the hospital stay will frequently cause emotional and practical problems for the family; however, the possibility of a full-blown thrombophlebitis occurring in the early postpartum weeks is a real one, and many fatalities from pulmonary embolism have occurred in the past under treatment without anticoagulants. It is incumbent on the physician to ensure adequate and thorough therapy, beginning while the patient is still in the hospital.

Anticoagulation during the Antepartum Period: We have successfully carried patients on long-term therapy *throughout* their pregnancy following a thrombophlebitis occurring early. There are also occasions when either a rheumatic heart or an embolic tendency will make anticoagulant therapy essential during the antepartum period. This treatment may be carried out with significant protection being afforded the mother against thromboembolism. If feasible, the anticoagulants may be discontinued about two weeks before the anticipated date of delivery, and allowed to taper off by themselves. If the risk of clotting is severe, an alternative is to continue anticoagulants at a lower level, aiming for a prothrombin time of twenty seconds (with a control of fifteen seconds) and then administering vitamin K_1 with the onset of labor. Immediately after delivery, therapy is reinstituted and continued for whatever length of time is indicated by the underlying disease. This regimen will impose a significant, but not prohibitive, risk on the fetus. In a review of antepartum thrombophlebitis cases at The New York Hospital, it has been found that of thirty-three mothers who received therapy during pregnancy, two fetal deaths were observed towards which the anticoagulation might have contributed. In both cases the anticoagulant therapy was thought to be excessive. The ultimate decision as to whether maximum protection should be afforded to the mother or to the unborn child must rest with the physician in attendance and the parents.

Prophylactic Anticoagulants: In mothers who have had attacks of active thrombophlebitis during previous pregnancies or at other times, in whose

legs the cords are still palpable, or who have large varicosities, the possibility of developing thrombophlebitis postpartum is sufficient to institute anticoagulant therapy on the second postpartum day and to continue it until the patient is ready to leave the hospital. By anticipatory treatment the likelihood of prolonging the hospital stay or risking any significant mortality from pulmonary embolism is virtually removed.

SELECTED REFERENCES

History

Wright, I S, Editor A History of Anticoagulants, A Symposium. New York, Grune & Stratton, 1959

General

Biggs, R., and Macfarlane, R G Human Blood Coagulation and Its Disorders Oxford, Blackwell Scientific Publications, 1954

British Medical Bulletin, 2 1955

Koller, T, and Merz, W R, Editors. I International Conference on Thrombosis and Embolism Basel, Switzerland, B Schwabe, 1954

Wright, I. S: The Pathogenesis and Treatment of Thrombosis, Circulation 5.161, February 1952

Heparin and Dicumarol

Jorpes, J E: Heparin in the Treatment of Thrombosis, An Account of Its Chemistry, Physiology and Application in Medicine London, Cumerlege

Verstraete, M., Clark, P, and Wright, I S Use of Different Tissue Thromboplastins in the Control of Anticoagulant Therapy, Circulation 16 213, 1957.

Thrombophlebitis

Wessler, S, and Deykin, D Theory and Practice in Acute Venous Thrombosis. A Reappraisal, Circulation 18 1181, 1958

Myocardial Infarction and Coronary Artery Disease

Bjerkelund, C J. The Effect of Long-Term Treatment with Dicumarol in Myocardial Infarction, Acta Med Scand Suppl 158, 1958

Ensor, R E, and Peters, H R Long-Term Anticoagulant Therapy in Coronary Disease, J A M A. 169 914, 1959

Nichol, E S, *et al* Long-Term Anticoagulant Therapy in Coronary Atherosclerosis, Am. Heart J. 55.42, 1958

Wright, I S, Marple, C. D, and Beck, D F Myocardial Infarction Its Clinical Manifestations and Treatment with Anticoagulants· Study of 1,031 Cases New York, Grune & Stratton, 1954

Rheumatic Heart Disease

Askey, J M: Systemic Arterial Embolism New York, Grune & Stratton, 1957

Cerebral Vascular Disease

A Classification and Outline of Cerebrovascular Diseases, Neurology 8: May 1958

McDevitt, E, Carter, S, Gatje, B, Foley, W, and Wright, I S: Use of Anticoagulants in Treatment of Cerebral Vascular Disease, J A M A 166 592, 1958

Millikan, C, Siekert, R, and Whisnant, J Anticoagulant Therapy in Cerebral Vascular Disease—Current Status, J A M A 166·587, 1958

Wright, I S., and Luckey, E H, Editors Cerebral Vascular Diseases. Transactions of Conference Held under Auspices of American Heart Association, Princeton, N. J, Jan 24-25, 1954 New York, Grune & Stratton, 1955

Wright, I S, and Millikan, C H, Editors Cerebral Vascular Diseases: Transactions of Second Conference Held under Auspices of American Heart Association, Princeton, N. J, January 16-18, 1957 New York, Grune & Stratton, 1958

Surgery

Miscall, L., Nolan, R., and Anderson, H.: Thromboembolism in Cardiac Surgery, West. J. Surg., In Press 1958.
Sturm, O., and Hansen, A.: Mitral Commissurotomy Performed during Anticoagulant Prophylaxis with Dicumarol, Circulation 12:981, 1955.

Obstetrics and Gynecology

Quenneville, Guy, Barton, Bennett, McDevitt, Ellen, and Wright, I. S.: The Use of Anticoagulants for Thrombophlebitis during Pregnancy, Am. J. Obst. & Gynec. In Press

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Relief of Pain in Angina Pectoris

The problem of the relief of the pain of angina pectoris has for a long time engaged the attention of the medical profession. However, the surgeon was not involved in its solution until Jonnesco,[1] basing his surgical procedure upon the experiments of Francois Franck,[2] sectioned the stellate ganglia and cervical sympathetic chain bilaterally in the neck and reported that the pain was completely relieved. But the inability of other surgeons to confirm these findings resulted in much discussion and research upon the sensory pathways leading from the heart.

Anatomy and Physiology: The sympathetic nervous system carries sensory impulses from and motor impulses to the heart. Intensive research has been performed to determine precisely what components of the thoracicocervical sympathetic system contain the sensory afferent fibers so that interruption of the minimal number of pain pathways produced the maximum amount of relief of the angina. A short review of the more recently acquired knowledge concerning the anatomy and physiology of the sensory pathways from the heart is necessary.

The presence of typical somatic afferent pathways in the sympathetic cardiac nerves seems clearly proven. Ranson and Billingsley[3] and Stohr[4] have described the histology of these fibers. Heinbecker[5] has confirmed these findings and shown further by the use of the cathode ray oscillograph that their conduction properties coincide exactly with those of the afferent fibers in the ordinary sensory nerves. In fact, in the strict sense these fibers are not of autonomic origin but are somatic fibers caught up in the sympathetic chain to carry afferent impulses from the heart to the sensory pathways in the spinal cord.

Stohr[4] has demonstrated sensory nerve endings in the heart muscle, endocardium, and epicardium, and in the adventitia of the coronary artery identical with those found in the heart and aorta. The sensory pathways from these endings pass along the periarterial plexus of the coronary arteries to the superficial and deep cardiac plexuses reaching the cervical ganglia of the sympathetic chain over the middle and inferior cardiac nerves. Since white rami connecting the cervical sympathetic chain and the spinal cord are lacking, the vast majority of these sensory fibers must pass down the chain to the upper thoracic ganglia, finally reaching their cells in the spinal ganglia through the white rami communicantes of the first thoracic and upper four or five intercostal nerves. The presence of these cervical cardiac nerves is well established. However, Brauecker[6] and Ionesco and Enachesco[7] have demonstrated the presence of thoracic cardiac nerves running directly across the posterior

mediastinum to the upper four or five thoracic sympathetic ganglia. Somatic afferent fibers are present in all these nerves. Apparently, therefore, the upper four or five thoracic sympathetic ganglia receive all the sensory pathways passing from the heart towards the spinal cord.

Blocking of Sensory Pathways: The problem now arises as to the evidence at hand concerning the safest and most effective way in which these sensory pathways can be blocked to cut off pain impulses from the heart. *Sutton and Lueth*[8] *showed by temporarily constricting the* descending branch of the left coronary artery in dogs that the characteristic signs of cardiac pain could be produced. Relief of the constriction resulted in rapid disappearance of the pain.

As experience with the results of surgery of the sympathetic system has increased, the effectiveness of a central, as compared to a peripheral, section of these nerves is apparent. Permanent and widespread interference with sympathetic function is far more certain after these nerves are sectioned at points where the complex peripheral plexuses are simplified in the paravertebral chains and spinal roots.

In recent years the surgical methods for relief of angina pectoris have narrowed down to two procedures, removal of the upper four thoracic sympathetic rami with their connections or section of the posterior spinal roots from the first to the fourth thoracic segments. Total thyroidectomy for relief of angina has been practically abandoned. The method of increasing collateral coronary circulation by the application of vascular grafts from adjacent intercostal muscles (Beck) carries too prohibitive a *mortality (thirty-seven per cent) to be justifiable.*[9]

The decision to operate upon a patient with angina requires courage and should be reached only after extensive study. However, given a patient who suffers from severe angina, especially angina decubitus, which cannot be controlled by appropriate medication, some effort must be made to relieve his intense distress. The patient, himself, of course, must make up his mind whether he can go on under medication alone with increasing discomfort or whether he is willing to accept the undoubted risk of surgical intervention.

The advantages and disadvantages of these two procedures, rhizotomy and laminectomy, are as follows:

Laminectomy must be carried out in the prone position which interferes with respiration and puts more strain on an already damaged myocardium. *But a laminectomy exposes the posterior roots bilaterally.* If both left and right sides of the precordium are involved, relief can be afforded by a single operation. Laminectomy and rhizotomy do not result in Horner's syndrome but do produce a bilateral thoracic anesthesia which is, at times, annoying. White[10] reports thirty cases from the literature with three deaths (ten per cent) and excellent results in all but one case. Lindgren and Olivecrona,[11] on the other hand, state that in seven cases rhizotomy failed to give complete and permanent relief. These authors feel that resection of the stellate and upper four thoracic ganglia is a much more effective maneuver for the relief of anginal pain. In their series of seventy-one cases, pain was completely relieved in thirty-one, or

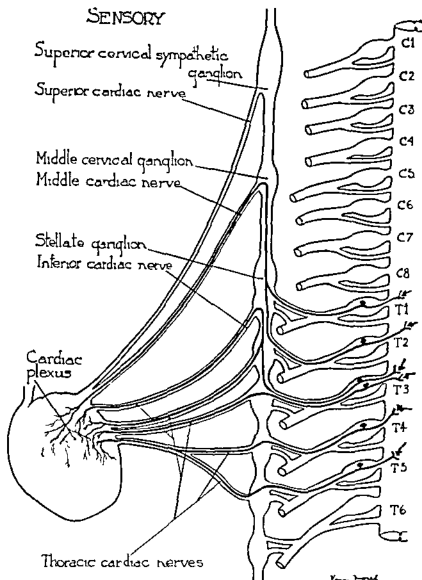


FIGURE 1 Diagrammatic representation of the cardiosensory pathways. These are true somatic afferent nerves, the ganglia of which lie in the posterior spinal root ganglia No sensory fibers pass through the superior cervical sympathetic ganglion. Note that all sensory fibers from the heart pass through the upper five thoracic sympathetic ganglia and enter the cord through the corresponding posterior spinal roots (Ochsner and DeBakey: Surgery)

43.7 per cent, and reduced to a milder form which could be satisfactorily controlled by medication in twenty-nine, or 40.8 per cent. Six patients died within one month of operation, a mortality of 8.5 per cent. Thoracic sympathectomy can be performed with the patient in the lateral position with less interference with respiration and hence, less myocardial strain. But, if the pain is bilateral, two such operations may be necessary. Horner's syndrome always follows—a negligible complication. But thoracic sympathectomy is definitely a surgical procedure requiring experience, whereas a general surgeon could readily carry out a laminectomy.

White[10] sums up the situation clearly when he states, "Those patients with a fair cardiac reserve may be subjected to laminectomy and root section with reasonable safety." This operation is most logical when the reference of cardiac pain is bilateral, or when the surgeon is not experienced in the technic of thoracic sympathectomy. For the more questionable risks, thoracic ganglionectomy is preferred, especially if the

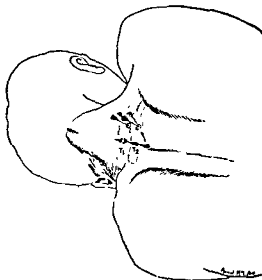


FIGURE 2 Paravertebral injection of thoracic sympathetic ganglia Bony landmarks for inserting needles (White. "The Autonomic Nervous System," The Macmillan Co.)

anginal pain is unilateral. For the poorest risk cases, those patients who have had repeated attacks of coronary infarction with large hearts and great reduction in cardiac reserve, interruption of the nerves by paravertebral alcohol blocks may be the only possible recourse.

Mandl,[12] Brunn[13] and Swetlow[14] have showed that a paravertebral block of the upper thoracic ganglia with alcohol would relieve the pain in angina pectoris. Mixter and White,[15] White,[16] Levy and Moore[17] and Marvin[18] have confirmed these observations. Ochsner and DeBakey[19] have reviewed the literature and tabulated the results in sixty-eight cases in which this procedure has been carried out. In this series alcohol injection produced complete or partial relief in 80.9 per cent; failed to relieve pain in 17.6 per cent and resulted in one death, a mortality rate of 1.5 per cent.

The indication for paravertebral block is intolerable pain from severe cardiac disease. Less acute pain from a less threatening heart lesion might conceivably be subjected to one of the three surgical measures for its relief. Since these patients are on the verge of catastrophe, the relatives should be warned that even alcohol block may result fatally. General anesthesia cannot be used for it masks evidence that the needles have been accurately placed. Careful preinjection medication is necessary to prevent psychic shock and dangerous distress during the procedure itself.

Sufficient barbiturates to insure a drowsy patient at the time of injection are indicated.

Technic: The instruments required are six, rustless, steel, flexible, lumbar, puncture needles, 10 cm. long. Bits of rubber tubing for depth markers and a metal centimeter rule should be included. A 10 cc. syringe which fits the needles closely and has a smooth action plunger should be used.

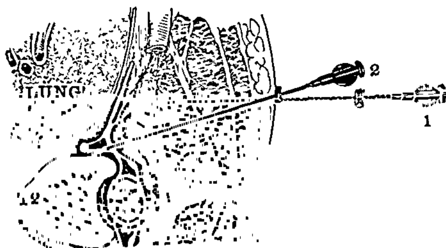


FIGURE 3 Paravertebral injection of thoracic sympathetic ganglia 1, 2, Method of inserting needles (White· "The Autonomic Nervous System," the Macmillan Co)

Hypodermic needles, one per cent and two per cent procaine hydrochloride without epinephrine, 50 cc. (1$\frac{2}{3}$ ounces) of absolute ethyl alcohol (C. P.), five per cent iodine and acriflavine to sterilize and mark the points of injection complete the outfit.

According to White,[17] the proper procedure for paravertebral injection is as follows: His technic is based upon that described by Labat.[21] The patient should be placed on his side on the edge of the bed, with the knees drawn up and the head flexed forward. The head should be supported by a pillow so that the cervical spine is held straight. The hands should be uncovered and made easy of access so that their comparative warmth and dryness may be determined. It is preferable to perform the injection with the patient in bed for any movement should be avoided for an hour following this procedure to permit the alcohol to become fixed in the tissues. Any lateral curvature of the cervical spine which may change the anatomic relationships of structures to be injected is to be avoided. Furthermore, no one should attempt this technic without ample experience upon cadavers. The dissecting or autopsy room is the place to learn this procedure before any attempt is made to apply it to a patient.

The bony landmarks for paravertebral injection are the spinous processes. Due to their imbrication like the shingles on a roof, the tip of each marks the level of the transverse process and the posterior angle of the rib next below. Thus the highest prominent vertebral spine, the

seventh cervical, marks the level of the first rib. This relationship holds over the entire length of the thoracic vertebrae. In thin individuals it is a very simple matter to locate the spines, but in the stocky type which so often goes with angina pectoris this may be a difficult matter. The points of injection are marked 3 to 4 cm. lateral to the spinous processes. Following the use of tincture of iodine, acriflavine applied with a fine cotton applicator is an excellent marking medium; the two substances combine to form a jet black sterile mark.

Needles 8 to 10 cm. long are inserted at the points so marked and pushed inwards perpendicular to the surface of the back. At a depth of 2 to 5 cm. the needles should touch the transverse process or the rib. It is a great help to have on each needle a depth marker consisting of a short length of small bore rubber tubing. The lower borders of the ribs are located and the depth markers pulled out to a distance of 3 cm. from the skin. The needles are then inclined slightly in a caudal direction and thrust down beneath the ribs at an angle of approximately 20 degrees towards the midline. Under these circumstances bone is usually felt again at a depth of 3 cm. beneath the ribs, evidence that the needle is in contact with the lateral aspect of the vertebra or the head of the corresponding rib. The sympathetic trunk lies at this depth running along the anterolateral aspect of the vertebra and looping over the heads of the ribs. Procaine injected in this region will diffuse freely through the retropleural areolar tissue, infiltrating the spinal nerves, the communicant sympathetic rami, and the ganglionated chain. The bony landmarks and the method of injection vary very little over the whole length of the dorsal spine.

In performing these injections, the needle should never be attached to the syringe. Care should be taken that the tip of a needle does not lie within the pleural cavity, in a blood vessel, or in an abnormal outward prolongation of the subarachnoid space. With the needle touching bone, it is almost impossible for its tip to be in the pleural cavity. Rapid inspiration of a drop of procaine placed in the shank of the needle or the production of a cough reflex on injecting the solution indicates that the needle tip has penetrated through the pleura. *Aspiration should always be attempted before injection. If the needle lies within* a blood vessel or the subarachnoid space, aspiration of blood or spinal fluid makes these complications obvious. None of these possibilities is dangerous provided the condition is looked for and recognized and the position of the needle changed.

As soon as the needles are inserted in the correct position, 2 cc. of two per cent procaine-epinephrine solution should be injected into each. Following this, and depending on the segments infiltrated, the characteristic signs of intercostal and sympathetic nerve paralysis should appear within a period of fifteen minutes. In case the upper four thoracic nerves are blocked, anesthesia should appear in the axilla, a short distance down the inner arm and over the third and fourth ribs. No skin anesthesia develops over the first and second ribs, as this region is also innervated by descending branches of the third and fourth cervical nerves. No

anesthesia should develop in the hand, but the entire arm, side of the neck, and head should become dry and distinctly hot. In addition to this, an accurate injection of the first thoracic ganglion should produce a well-defined Horner's sign. After injections in the lower dorsal region, loss of sweating and intercostal nerve anesthesia coincide with the segments infiltrated.

In case these signs fail to develop, the needles should be readjusted and an additional cubic centimeter of procaine solution injected into each, but a total of 3 cc. should never be exceeded. The reason for this is important. Greater amounts of procaine spread so far in the tissues that they may produce characteristic signs of sympathetic paralysis, whereas 5 cc. of alcohol subsequently injected will fail to destroy the desired rami. When 3 cc. of procaine fail to produce rapid and clear-cut paralysis, it is better to withdraw the needles and try again on another day.

When satisfied that the needles are correctly placed, it is best to inject 2 to 3 cc. more procaine into each (one per cent procaine, rather than two per cent). This supplementary infiltration is to ensure a widespread anesthesia, so that the final injection of alcohol will be painless. Some writers have advised the injection of alcohol under a general anesthetic, claiming that this avoids pain on injection and prevents dilution of the alcohol. This technic loses the localizing advantages of the primary injection of small amounts of procaine. When additional procaine is injected secondarily up to a total of 5 cc. for each needle, a slow, careful injection of the alcohol is rarely painful. The argument that dilution of the alcohol prevents effective destruction of the nerves does not seem reasonable since fifty per cent alcohol is supposed to penetrate tissues better than ninety-five per cent.

The final injection of ninety-five per cent alcohol is carried out by instilling 5 cc. very slowly through each needle. It is well to test out each needle again by aspiration to make sure its tip cannot have moved and penetrated a blood vessel or a prolongation of the subarachnoid space. If the patient complains of any burning pain along the course of an intercostal nerve, the injection must be stopped for a few minutes until the discomfort subsides. By taking sufficient time it is usually possible to carry out these injections with little discomfort to the patient. In order to mark the position of the alcohol 0.25 cc. of lipiodol may be injected through the highest and lowest needles. This minor addition to the procedure gives a very exact idea of the position of the alcohol at a subsequent x-ray examination. The needles are then withdrawn.

In order to minimize diffusion of the alcohol it is best to keep the patient as quiet as possible for an hour following the injection. He may then be permitted to shift over on his back and have the bed rest elevated to any angle that he desires. Most patients can be up in a chair on the following day and leave the hospital within seventy-two hours.

Results and Sequelae: Our records contain thirty-seven cases in which cervicothoracic paravertebral block has been performed. Among these are but seven instances in which the procedure was carried through for relief of anginal pain Four of these were completely relieved for four, five, nine,

and eleven months. Three of these cases succumbed to their cardiac lesions without recurrence of pain. One patient cannot be traced. A fifth patient was possibly fifty per cent improved for the two months he lived. In the other two cases, in which the procedure was used to stop anginal pain, the ganglia could not be successfully injected. Among these thirty-seven cases a Horner's syndrome and increase in temperature in the corresponding hand lasting more than six months was produced in twenty-one In seven, evidence of sympathetic block was present for ten days to two weeks and then disappeared. In one case in which the injection was performed to relieve causalgia in the hand and arm, a fatality occurred. Three needles had been introduced to block the first, second and third thoracic sympathetic ganglia. Aspiration of the needles showed that they were neither in the pleura, the subarachnoid space nor a vein. Two cubic centimeters of two per cent procaine had been injected into the needle opposite the seventh cervical vertebral spine. As a Horner's syndrome appeared the patient complained of respiratory difficulty. In less than a minute his respirations ceased and could not be restored. Immediate autopsy showed that he had marked emphysema with upward dilatation of the dome of the pleura. The needle had crossed the pleural cavity in reaching the sympathetic chain. Death was ascribed to a pleuropulmonary reflex. My own opinion is that the needle tip might have slipped deeper as the procaine was injected and entered the subarachnoid space. In this way the procaine reached the medulla and caused a respiratory collapse. I have had referred to me two patients in whom alcohol had inadvertently been injected into the subarachnoid space during this procedure. In one instance a complete transverse lesion of the cord resulted, in the other marked weakness of the leg and mild sphincter disturbance.

Another unfortunate sequela of this procedure is a persistent neuritic pain due to irritation of the first or second thoracic nerves by the alcohol. Five of our thirty-seven patients complained of this distress although fortunately it disappeared in four to six months. In six instances a mild pneumothorax in two combined with a slight friction rub and a slight amount of pleural pain was recorded.

I have had occasion to remove the cervicothoracic chain in two patients who had been injected four and seven months previously with apparent success. I could not see that the injection had produced adhesions which made subsequent ganglionectomy more difficult.

If successful, alcohol block of the three or four upper thoracic sympathetic ganglia will relieve anginal pain. In experienced careful hands, the procedure is safe. About fifty per cent of these patients can be completely relieved of their pain, another thirty per cent benefited. In these cases major surgery may impose too great a strain upon an already crippled myocardium. Paravertebral sympathetic block with alcohol should be given primary consideration as a method for the relief of anginal pain.

REFERENCES

1. Jonnesco, T.· Bull. Acad de med 84.93, 1920.
2 Franck, Francois Bull Acad de med 41·565, 1899
3 Ranson, S W., and Billingsley, P. R.· J Comp Neurol. 29·313, 1918.

4. Stohr, P., Jr.: "Mikroscopische Anatomie des vegetativen Nervensystems," Julius Springer, Berlin, 1928.
5. Heinbecker, P.: J. Thoracic Surg 2.517, 1932-33.
6. Brauecker, W.: Beitr. z. klin. Tuberk. 66:1, 1927.
7. Ionesco, D , and Enachesco, M.: Compt rend Soc. de Biol 97:977, 1927
8. Sutton, D C., and Lueth, H. C.: Arch. Int. Med. 45:827, 1930.
9. Beck, Claude, S : Ann. Surg 118.788, 1943.
10. White, J. C., and Bland, E. F.: Medicine 27:1, 1948.
11. Lindgren, I , and Olivecrona, H : J. Neurosurg 4:19, 1947.
12. Mandl, F.: Wien. klin. Wchnschr 38:759, 1925, 49:531, 1936
13. Brunn, F.: Wien. klin. Wchnschr. 39:1110, 1926.
14. Swetlow, G. I.: Am. Heart J. 1:393, 1925-1926.
15. Mixter, W. J , and White, J. C.: Ann. Surg. 89:199, 1929
16. White, J. C.: J.A M A. 99:10, 1932.
17. Levy, R. L., and Moore, R L. Arch Int. Med. 48 146, 1931
18. Marvin, H. M.: Bull. New York Acad. Med. 11:453, 1935.
19. Ochsner, A , and DeBakey, M.: Surgery 2:428 (Sept.) 1937.
20. White, J. C.: "The Autonomic Nervous System," The Macmillan Company, New York, 1935.
21. Labat, G : "Regional Anesthesia," W. B. Saunders Co , Philadelphia, 1928.

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Nourishment of the Heart by Channels Other than the Coronary Arteries

Introduction: Nourishment of the heart by channels other than through the coronary arteries was first suggested by the work of Pratt.[1] His work, together with the more recent observations of Kretz,[2] Wearn,[3] and Grant and Viko,[4] has aroused considerable interest in the problem of cardiac nourishment. The observation that the heart may be nourished by channels other than the coronary arteries has been given confirmation by the finding of hearts where both coronary arteries were occluded by chronic processes.[1,2,5,6]

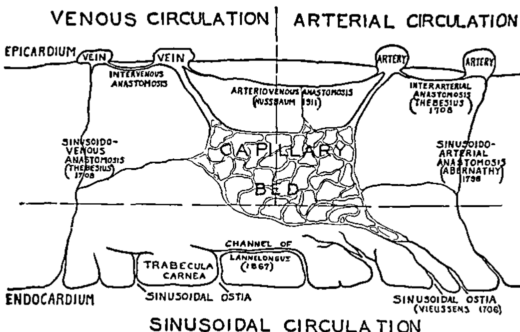
Although the occlusion had apparently been complete for many months, the history of these patients revealed that they had been able to perform considerable work up to the time of death. Death in these cases had usually been sudden. Cases had also been observed at postmortem examination in which the mouth of one coronary artery was occluded by atheroma and the other coronary artery partially stenosed, and yet, according to the history, the patients had been able to continue their work for a considerable period before death. The myocardial damage in these cases is much less than would be expected and infarction is often strangely absent.

There are three possible means of cardiac nourishment other than the coronary artery:

1. The extracardiac anastomoses
2. The thebesian vessels.
3. Reversal of flow in the coronary veins.

The myocardial circulation can best be understood by following its embryological development. The irrigation of the embryo's heart is first accomplished by the muscle being perfused through sponge-like sinusoidal spaces which receive their blood from the cavity of the heart iself. It is these openings into the sinusoidal spaces, still persistent in the adult (although considerably narrowed and in some instances almost obliterated), that are commonly called venae minimae cordis, or the veins of Thebesius. The next cardiac vessels to appear are the veins which branch into the substance of the myocardium. Their development is followed by budding of the arteries which likewise ramify in the embryonic heart wall. The finer terminations of both venous and arterial sprouts are capillary in character, but true capillaries cannot be said to be present until the developing arterial and venous capillaries have joined with each other

and with the sinusoidal (thebesian) circulation. Now, for the first time (in rabbit embryos of 17 mm. in length at about the third week of fetal life) can blood follow the traditional elementary circuit of artery, capillary, and vein.



Diagra[illegible]
origin an[illegible]
with thes[illegible]
vascular[illegible]
the epicardial venous vessels develop next, and, finally, the epicardial arterial vessels develop and join the other two, forming a common capillary bed. The endocardial or epicardial origin of the vessels, as well as their various modes of [illegible]

[illegible]

The notion of a small artery ending in a capillary and this, in turn, drained by a small vein is an elementary one which peculiarly persists as far as the heart is concerned, although for 300 years attempts have been made to show its inadequacy. On the arterial side, the presence of a rich anastomosis between the coronary arteries has been definitely established by the work of Spalteholz,[7] Nussbaum,[8] and Gross.[9] The maximum size of these connections is still in doubt, but it is probable that they may

attain an arteriolar size. The presence of intravenous anastomoses is a matter of common knowledge. Arteriovenous anastomoses* are known to be present elsewhere in the body and have been seen by Nussbaum[8] in the heart. He believes that this system which he found in the epicardium serves to transmit blood from the arteries to the veins during systole when the capillaries are contracted. The number and frequency of these anastomoses have as yet not been entirely worked out in the human heart.

In 1947, Prinzmetal, Simkin, Bergman, and Kruger, by the injection of microspheres of various sizes, observed the appearance of glass spheres 70 to 170 micra in diameter from the coronary sinus following the injection of the spheres into the left or right coronary arteries. These suggest the presence of arteriovenous anastomoses which may attain the size of 170 micra.

EXTRACARDIAC ANASTOMOSES

Von Langer[16] gave a complete account of the extracardiac anastomoses. The most important extracardiac arterial connections seem to be the communication between the coronary arteries and the bronchial arteries through the capillaries of the vasa vasorum of the first part of the aorta and the pulmonary artery. Because the occlusion of the ostia of the coronary arteries has been frequently accompanied by an obliteration of the lumina of the vessels for some distance beyond the point of origin, the extracardiac connection with the vasa vasorum of the great vessels could not be essential for maintaining the circulation in these cases. The capillary bed of the aorta in the region of the sinuses of Valsalva is so small that it would seem that such anastomoses could nourish at best but a small portion of the myocardium

A third group of vascular channels which are believed to have considerable importance in the myocardial nutrition upon closure of the coronary arteries are the thebesian vessels.

THE THEBESIAN VESSELS

The discovery of thebesian vessels was credited to Vieussens,[11] but the first full description was by Thebesius[12] in 1708, since that time, many investigators, Haller,[13] Abernathy,[14] Bochdelak,[15] Langer,[16] Pratt,[1] Kretz,[2] Wearn,[3] Grant and Viko,[4] have studied their anatomic connections and physiology. Their presence has usually been determined by the injection of various substances, air, water, mercury, waxes, celloidin, together with dissection or corrosion, and by perfusion experiments.

According to Grant and Viko,[4] there are three main types of thebesian vessels. These, however, merge one into the other. These are: (1) Vessels subdividing into trees ending in a capillary network and ramifying in the endocardium of the underlying muscle. (2) Channels uniting neighboring foramina, and showing all variations from fine anastomoses between neighboring trees and intertrabecular spaces. (3) Vessels uniting fora-

* Halpert[10] has reported a case of cardiac arteriovenous aneurysm which consisted in a wide communication between the aorta and the right atrium, and which was unassociated with cardiac disturbance during life

with the coronary veins and showing all variations from fine anastomoses between the thebesian tree and coronary vein to direct communication of the coronary vein and the ventricle.

The ostia of the thebesian vessels are observed as small depressions or crypts in the endocardium of both auricles and ventricles. However, they are more numerous in the right ventricle, especially toward the apex and in the papillary muscles.

Embryology: The embryology and physiology of the intertrabecular or sinusoidal spaces have been investigated by Lewis[17] and by Grant.[18] Very early in embryonic development (in rabbit embryos 8.5 mm. in length) the myocardium of the auricle is seen to be pierced by endothelial outgrowths which form capillary spaces between the muscle and epicardium. Similar outgrowths later appear from the outer portion of the ventricle, forming epicardial capillaries, which are extensions from previously existing intertrabecular spaces or sinusoids of the ventricles. Grant[18] found that in embryos of 17 to 20 mm. the intertrabecular spaces are present as wide spaces between the growing muscle bundles, but their continuation into the compact myocardium cannot be distinguished from the fine ramifications of the veins and arteries there, and all three vascular structures together appear as a capillary network in that region.

According to Lewis,[17] further development is marked by a continuous growth of the arteries and veins, and by a regression of the intertrabecular spaces; the muscle columns, coming together, reduce many of the spaces to strands of epithelium without lumen.* Grant[18] has been unable to satisfy himself that actual obliteration takes place. It seems to be quite generally agreed that the sinusoidal circulation is replaced by the coronary circulation. According to Grant,[18] the outermost intertrabecular spaces are narrowed down by the compact myocardium to capillary tubes which are joined by the coronary vessels extending inward to the epicardium. The capillaries arising from the central and inner intertrabecular spaces retain their connections with the ventricles. The ventricular communications persist in the adult as the thebesian vessels of the ventricle.

Anatomic Connections and Physiology: The thebesian vessels connect the ventricles and the coronary veins by channels of very large size. This has been shown very conclusively by the ease with which various preparations of thick consistency injected into the coronary sinus reach the ventricular chambers. The connection between the coronary arteries and the ventricular chamber is still questionable. Most investigators have been able to show only a capillary connection. However, Abernathy[14] and Wearn[3] believe that these connections are arteriolar in size.

Where both coronary arteries have been occluded, it is the belief that the myocardium receives its nourishment through the thebesian vessels. If the occlusion is a gradual one, nutrition by this means would be favored. Under such conditions the flow of blood would be away from the ventricu-

* Grant[19] and Bellet and Gouley[20] have each reported cases of a congenitally malformed heart in which there was a persistence of the sinusoids after fetal life. Connections were traced by serial section between them and the coronary vessels.

lar chambers into the coronary vessels. The belief that the heart may be nourished by the thebesian vessels rests chiefly upon two series of experiments: (1) The injection of various masses into dead hearts showing the connections, by means of the thebesian vessels, of the ventricles on the one hand and the coronary arteries and veins on the other; and (2) the successful perfusion of the isolated heart through the thebesian channels.

Most authors supporting the theory of cardiac nourishment by the thebesian vessels believe that these channels are filled at the beginning of systole. In view of the fact that double coronary artery occlusion was observed in certain specimens, and in consideration of the work before mentioned, the explanation of cardiac nourishment by the thebesian vessels was accepted as the only adequate explanation by which the heart could be nourished under such conditions.

NOURISHMENT BY REVERSAL OF FLOW IN THE CARDIAC VEINS

In the endeavor to determine the direction of blood flow in the cardiac chambers, Batson and Bellet[21] performed a series of experiments in the intact animal whereby particulate matter was injected into the peripheral veins toward the heart. The particles were of such size that they could not pass through the lung capillaries. The particles were uniformly found in the coronary sinus and the cardiac veins. Under the conditions of the experiment, namely, with a normal or a rising intra-auricular pressure and a falling coronary artery pressure, a reversal of flow occurred in the coronary veins. It is well to remember in this connection that the valve of the coronary sinus is insufficient in ninety-six per cent of cases.[22,23] These experiments suggested that *in cases of double coronary artery occlusion*, with a zero pressure of the coronary arteries the flow of blood during atrial systole is toward the capillary bed. They believe that the blood (under the conditions of the experiment) enters the cardiac veins during atrial systole, from which it may flow in part into the ventricular chambers through the thebesian channels, as well as into the capillary bed. With the onset of ventricular systole, the blood is forced from the capillary bed.

It should be recalled that Pratt[1] was able to maintain the heartbeat for a considerable period by perfusion through the coronary sinus.

That the heart may be nourished by venous blood is shown by the large number of congenital hearts where life is sustained for a considerable period of time by blood which is largely venous. It is not difficult to understand how the nourishment of the myocardium can be maintained by venous blood when it is recalled that the oxygen tension of venous blood ranges from sixty to seventy per cent, while the figure for arterial blood is ninety-five per cent.

These authors believe that the reversal of flow may be an adjunct in maintaining cardiac nourishment in cases of coronary occlusion. They also suggest that the reversal of flow in the coronary veins by irrigation of the formerly anoxemic areas could explain the relief of pain in angina with the onset of decompensation and, by helping to maintain the cardiac nutrition for a brief period, the occasional spontaneous recoveries from ventricular fibrillation.

ARTIFICIAL PRODUCTION OF AN ACCESSORY CIRCULATION OF THE HEART MUSCLE

In view of the great incidence of coronary occlusion, various procedures, mostly experimental, have been tried in an endeavor to improve the myocardial circulation in the presence of occlusion of the coronary arteries. Hudson, Moritz, and Wearn[26] observed widespread anastomosis of the auricular branches and the coronary branches to the pericardial fat and the pericardiophrenic branches of the internal mammary arteries and the anterior mediastinal, pericardial, bronchial, superior and inferior phrenic, intercostal, and esophageal branches of the aorta. They were able not only by coronary injection to inject the surrounding structures, but also to show vessels in the heart injected through the thoracic branches of the aorta. They believe that this extracardiac collateral circulation is probably of significance in compensating for sclerosis of the large trunk of the coronary arteries.

That the extracardiac anastomosis was increased by the presence of pericardial adhesions was shown by Moritz, Hudson, and Orgain.[27] They observed a rich injection of the parietal pericardium and injected vessels were observed extending from the epicardium to the parietal pericardium. These studies suggested that the reserve for cardiac circulation would be increased by the presence of pericardial adhesions.

Encouraged by these results, Beck and his co-workers[24,25] performed experiments on dogs whereby a collateral circulation to the myocardium was produced by grafting tissue on to the myocardium. The principle consists of the vascularization of an organ by the establishment of a collateral arterial or arteriolar bed. It involves the union of blood vessels that are too small for anastomosis by means of surgical suture. It can be regarded as a type of *plastic operation*, the nearest approach to which is the Talma-Morison operation for cirrhosis of the liver. The latter involves venous rather than arterial anastomosis

After successfully performing such an operation in dogs, Beck proceeded to operate on patients. The operation consists in grafting a part of the pectoral muscle onto the myocardium. The lining of the parietal pericardium is roughened everywhere so that it can become adherent to the myocardium. Experimentally, in dogs it was possible to occlude completely the entire coronary supply except the septal branch, with recovery of the animal and without the production of infarction.

Of the first twenty-five patients operated upon by Beck, ten have died. The results in the patients who survived the operation were at first quite encouraging Later results, however, have not come up to the original expectations.

New Method for Increasing the Blood Supply to the Heart Muscle: A number of attempts have been made to increase the blood supply to the heart muscle in cases of coronary artery disease. The various procedures used are described below.

Gross[28] observed a conspicuous increase in the extent of the vascular blood after coronary sinus ligation in dogs. This method has been applied to a few human patients, but the results have not been particularly en-

couraging. In 1938 O'Shaughnessy,[32,33,34] utilizing omentum brought up through the diaphragm as a source of blood supply, operated on twenty patients, with six deaths. Nine of the survivors were asymptomatic. Thompson and Raisbeck in 1942 utilized talc to produce vascular adhesions between the heart and pericardium.[35] Thompson's latest report comprised thirty-eight patients with good results in seventy per cent and a 15.8 per cent mortality rate.[36] Fauteux has attempted to relieve anginal pain by pericoronary neurectomy combined with ligation of the coronary sinus to increase the amount of blood available to the myocardium. His clinical cases in his 1946 report numbered sixteen, with three operative deaths.[38] Eleven patients were alive with objective improvement three months to six and a half years after operation. More recently he has published studies on anastomoses of the internal mammary artery with the coronary sinus and anastomosis of the right auricle with the pulmonary artery above the pulmonary valves, but no clinical data were given.[41] Vineberg[43,44] has reported experimental studies on the production of vascular anastomoses through implantation of the internal mammary artery directly into the myocardial wall of the left ventricle. There has been no clinical application of these studies. Lezius in 1939 utilized the lung experimentally as a source of blood to the heart.[45] O'Shaughnessy used this procedure in one patient with decided improvement. Carter[31] modified Lezius' operation and, after considerable experimental work in which undoubted numerous new vascular channels were demonstrated, operated on two human beings. One of these patients, operated on one year ago, was decidedly improved, and the other died of a massive infection thirty-six hours after operation.

Another method for revascularization of the heart has been presented by Beck.[30] This method consists of arterialization of the sinus. Arterialization of the coronary sinus was accomplished by grafting a systemic artery into the sinus and also by making a new branch from the aorta to the sinus, using a free graft of artery or vein. Arterialization of the coronary sinus was effective physiologically. After anastomosis was made it was possible to ligate a major coronary artery in dogs with little or no more mortality and with little or no infarction. One patient with severe coronary artery disease was operated upon. A free graft of brachial artery was placed between aorta and coronary sinus A fresh infarct developed in the interventricular septum probably at the time of operation. The anastomosis was patent at the time of death one day later.

These procedures indicate the many attempts that are being made to increase the blood supply to the heart muscle in patients with a precarious coronary blood supply. Unfortunately these procedures are hazardous and their efficacy still remains to be proved.

SUMMARY

In summarizing, there are three possible means of cardiac nourishment in occlusion of both coronary arteries: (1) By the extracardiac anastomoses, (2) by the thebesian vessels, and (3) by the reversal of flow in the coronary veins. The possibility of cardiac nourishment from these

sources is discussed. Unfortunately some of these procedures are hazardous and their efficacy still remains to be proved.

REFERENCES

1 Pratt, F H Am J Phys 1:86, 1898
2 Kretz, J Virchow's Arch f. path. Anat 266.647, 1928
3 Wearn, J T J Exper Med 47:293 (Feb. 1) 1929
4 Grant, R T, and Viko, L E. Heart 15:103 (Aug) 1929
5 Leary, T, and Wearn, J. T Am Heart J 5·412 (April) 1930.
6 Cabot, R C, and Mallory, T B: New England M J 202.287 (Feb 6) 1930
7 Spalteholz "Die Arterien der Herzwand," S Hirzel, Leipzig, 1924
8 Nussbaum, A Arch f. Mikro. Anat 80 450, 1912
9 Gross, L "The Blood Supply to the Heart," Paul B Hoeber, New York, 1921.
10 Halpert, B Heart 15.129 (May) 1930
11 Vieussens, R: "Nouvelle deconvertes sur le coeur," Toulouse, 1706
12 Thebesius, A C: "Dissertatio de circulo sanguinis in corde," Lugduni Batavorum, 1708
13 Von Haller. *"First Line of Physiology," Cullen Translation, 1·75*
14 Abernathy Philosophical Transactions, 287, London, 1798
15 Bochdelak, V. A Arch f. Anat, 302, 1868
16 Von Langer, L Sitz. d Kais Akad d Wiss, Wien 3 Abt 82·25, 1880
17 Lewis, F T Anat Anz 25 261, 1904
18 Grant, R. T Heart 13 261 (Dec) 1926
19 Grant, R. T.· *Ibid* 13 273 (Dec) 1926
20 Bellet, S, and Gouley, B A. Am J Med Sc 183 455 (April) 1932
21 Batson, O V, and Bellet, S· Am Heart J. 6 206 (Dec) 1930.
22 Poirier, Charpy, et Nicoles "Traité d'Anatomie humaine," Tome II Angéiologie, Paris, 1912
23 Yater, W M Arch Path 7 418 (March) 1929
24 Beck, C S Ann Surg 102 80 (Nov) 1935
25 Beck, C S, and Tichy, V L. Am Heart J. 10 849 (Oct) 1935.
26 Hudson, C L. Moritz, A R, and Wearn, J T J Exper Med 56·919 (Dec) 1932
27 Moritz, A R, Hudson, C L, and Orgain, E. S *Ibid* 56.927 (Dec) 1932.
28 Gross, L, and Blum, L Proc Soc Exper Biol and Med 32 1578 (June) 1935
29 Prinzmetal, M, Simkin, B, Bergman, H C., and Kruger, H E. Am. Heart J. 33 420, 1947
30 Beck, C S., Stanton, E, Batiuchok, W, and Leiter, E· J A M A 137·436 (May 29) 1948
31 Carter, B N: J A M A 138 1207 (Dec 25) 1948.
32 Davies, D T, Mansell, H E, and O'Shaughnessy, L Lancet 1 1, 76, 1938
33 O'Shaughnessy, L Lancet 1·185, 1937.
34 O'Shaughnessy, L, Slome, D, and Watson, F: Lancet 1.617, 1939
35 Thompson, S A, and Raisbeck, M J Ann Int Med 16.495, 1942
36 Thompson, S A In discussion on Stanton, Schildt, and Beck at American Surgical Association (May) 1948
37 Schildt, P, Stanton, E, and Beck, C S Ann Surg 118 34, 1943
38 Fauteux, M. Surg, Gynec. & Obst 71·151, 1940
39 Fauteux, M.· Am Heart J 31·260, 1946
40 Fauteux, M· Ann Surg 124.1041, 1946
41. Fauteux, M: Rev canad de biol 5·252, 1946
42. Fauteux, M: Rev canad de biol 5:252, 1926.
43 Vineberg, A M. Canad M A J 55.117, 1946
44 Vineberg, A M. Development of Anastomosis between Coronary Vessels and Transplanted Internal Mammary Artery Read before the American Association for Thoracic Surgery (June 2) 1948
45. Lezius, A: Arch f klin. Chir. 191·101, 1938.

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Disturbances of the Heart Beat

General Considerations: A disorder of the heart beat is usually one of the first abnormalities to come to the physician's attention in the examination of a patient. The traditional *"entre,"* the accepted primary professional gesture of palpation of the pulse, often yields significant evidence to the trained fingers of the alert examiner. Much valuable information may be elicited in an intelligent study of the pulse even while listening to the patient's complaints, while developing the symptom complex, and while obtaining the historical past and etiologic facts volunteered by the patient. Palpation of the pulse must not be, as it all too often is, merely an expression of friendliness, a reassuring move, a vestige of the ancient and honorable art of laying on of the hand that was the practice of medicine.

The pioneer work of Mackenzie with the polygraph and Einthoven and Lewis' study with the electrocardiographic method of precision have clarified the subject. The diagnosis of disturbances in the pulse, dependent upon disorders in the cardiac mechanism or heart beat, is one of the most scientifically exact in medical practice. Present knowledge is such that at the bedside an accurate interpretation of disorders of the pulse and heart beat can be made one of the most precise parts of the physical examination. The author hopes to be able to demonstrate these facts in the following discussion.

Symptoms: The commonest disturbances of the cardiac mechanism are fortunately those that are of least serious or symptomatic significance. They may give rise, especially in the neurotic patient, to a long train of symptoms and may thus dominate the clinical picture. On the other hand, in more stolid individuals, even a severe disturbance may be recognized only as a slightly peculiar fluttering sensation or a slightly unusual throbbing. The effects may be only of a momentary or transient nature, may recur in paroxysms of shorter or longer duration, or may be sudden in onset and sudden in offset, more or less persistent and permanently established.

The symptoms that arise in these conditions in general are usually due to the peripheral sensitiveness or hypersensitiveness of the individual nervous patient. Palpitation, apprehension even to panic, and anxiety in the uninitiated, weakness, giddiness, vertigo, syncope, precordial distress, discomfort even to angina, dyspnea, lethargy, delirium, coma, convulsion and exitus may be the result of the more serious disorders.

In some of the severe types, however, there is a distinct change in the functional efficiency of the heart as a result of mechanism disturbances,

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and the total blood flow is undoubtedly often seriously interfered with. Under such circumstances, the patient usually complains of the symptoms of myocardial insufficiency, as dyspnea, orthopnea, and edema of congestive heart failure, or pain, rather than of the sensations that might be created by the mechanism abnormality.

The pathologic anatomy may, however, be insignificant or rather non-demonstrable, consisting of slight physical or chemical intracellular or intercellular changes which would produce little if any abnormal staining reaction, and consequently may escape even the most careful microscopic study. Then, again, gross or microscopically demonstrable, postmortem, anatomic, or histologic abnormalities cannot always be held directly responsible for the mechanism disturbance that had been present before the patient's death Under certain circumstances in which lesions are present in the primary conduction pathways of the heart, it is justified to assume a causative relationship.

Direct and primary changes in the vascular bed and circulation of the heart itself are often found causing damage that may be localized to minute points, but usually these affect widespread and diffuse areas throughout the myocardium. There may be evidence only of disease in another organ or part of the body which, however, is known to affect the heart directly or indirectly Central or reflex nervous influences, from the respiratory or circulatory system as pleural or carotid sinus areas may cause cardiac mechanism disorders.

Interpretation or evaluation of the findings must be made with due regard to a general survey of the cardiovascular system in respect to the pathologic physiology of the disease that is found The mechanism disturbances may be of paramount importance and call for measures directed primarily toward their alleviation Nevertheless, they cannot be considered as distinctive clinical entities in themselves, but merely as signs expressing the effect of a disease process on the heart. Such heart disease may be entirely of nervous origin or may be the result of the general effects the disease has had on the vital organ.

Examination of the Pulse and the Heart Beat: The phenomena that may be detected in the peripheral arteries, the temporals, carotids, brachials, radials, femorals, popliteals, dorsalis pedis, and posterior tibials, are the direct results of left ventricular activities that have been propagated into the periphery through the arterial system The examination begins with palpation of the pulse in the radial artery with the arm at the side and with it raised above the level of the heart The rate and the rhythm of the pulse wave are taken into account, also the volume, tension, sustaining power, and, in general, the form of the pulse wave. Note should be made whether it is a dicrotic or an anacrotic pulse, whether well sustained or poorly sustained, slow plateau or bounding, quick, or collapsing. The brachial, but especially the carotid, should also be carefully examined and the apex of the heart simultaneously palpated and auscultated. The A, C, and V waves in the veins of the neck are often of some significance and should be noted. These waves are usually seen in the jugular bulb region in thin-necked individuals. The character of the venous pulse wave is of

some significance in the differential diagnosis of mechanism disturbances.

After examination at rest, the patient is asked to perform some respiratory maneuvers as (1) breath-holding at the end of a deep inspiration without and with expiratory effort against a closed glottis (Valsalva), (2) inspiratory effort through a closed glottis (Müller), (3) prolonged breath-holding, (4) hyperventilation and subsequent breath-holding. These maneuvers may produce arrhythmias and even syncope, and should be done first in the recumbent and then in the standing position. A fifteen-minute orthostatic tolerance test and a fifteen-second massage of the carotid sinus is done and the results noted. *Atropine* 1/50 grain (1.2 mg.) will usually erase the arrhythmias or prevent them. The patient's heart rate if slow should be increased by exercise if he can tolerate it, or by the use of amyl nitrite, nitroglycerin, or atropine. If the rate is primarily high, the effects of carotid sinus pressure should be noted. The general nervous reaction of the patient is of considerable significance in the evaluation of findings, especially in the presence of a rapid pulse.

The examination of the heart should always be carried out with simultaneous palpation of the carotid pulse. In this way, and only in this way, is it absolutely possible to localize and identify the first and second heart sounds, the systolic and diastolic periods of the heart beat. The disturbances that fail to open the aortic valve are thus detected, for the auscultatory phenomena will be heard over the heart but no accompanying wave will be palpated in the carotid. This dissipation of cardiac energy without any peripheral effect is commonly present in serious irregularities or arrhythmias

Cardiac mechanism disturbances may be analyzed and for the most part accurately diagnosed by the ordinary bedside methods that are available to every practitioner. Confirmatory evidence always should be sought in the electrocardiograms. There are, unfortunately, a few disturbances that defy complete analysis by any other than the electrocardiographic method.

Emphasis will be placed upon the methods of physical examination, inspection, palpation, and auscultation of the activities of the apex and the carotid pulse at rest and under stress. The electrocardiographic method is the court of last appeal and should be applied as a corroborative method whenever it is available. Present bedside methods are the fruits of the electrocardiographic method of precision in the hands of experts Frequent corroboration, checks, and tests tend to sharpen the diagnostic acumen of the modern, scientific physician. The polygraphic method has been almost entirely abandoned because of the difficulty and unreliability of the technical procedure and the greater uncertainty in interpretation of the polygram as compared with the simplicity of the electrocardiogram.

To establish a diagnosis it may be necessary to repeat the examination after the application of the blood pressure cuff or following exercise or carotid pressure, or the administration of amyl nitrite, nitroglycerin, atropine, Adrenalin or Prostigmin. The disturbances and their characteristics may be learned by rote and the diagnoses made by rule of thumb; the general characteristics of the disturbances are sufficient for fairly accurate interpretation of the disorders. It is, however, much easier and safer to visualize the mechanism disturbances in terms of the normal and patho-

logic physiology of the origin and propagation of the excitatory impulses over the heart and in terms of the associated mechanical contractions and waves.

Special Anatomy and Physiology of the Heart: It is desirable to review briefly the specialized anatomy and physiology of the heart to insure an adequate conception of the subject when it is presented to those who have not made a particular study of it. In the first place, there are certain structures in the heart that are practically submerged and are not demonstrable in the gross examination of even the large adult human heart. Microscopically, these important structures are seen to consist of rather small, pale, embryonic-like heart muscle cells with some neuromuscular tissue and in some areas endings of nerve fibers and ganglion cells lying just beneath the endocardium.

The first structure of importance is the sinoatrial (S-A) node, a small mass of tissue about 2 cm. long and 2 mm. in width. It is somewhat comma-shaped and is embedded in the upper part of the sulcus terminalis, the groove between the junction of the superior vena cava and the right atrial appendage. It is sometimes called the Keith-Flack node after its discoverers and is found to be made up of striated fibers, containing uniform and well-marked elongated nuclei, fascicular in arrangement and imbedded in densely packed connective tissue. The cells are smaller than those of ordinary atrial muscle, are richer in glycogen, and are supplied with fibers derived from the vagus and sympathetic nerves. This sinoatrial node is quite properly named the *pacemaker*. Vagus stimulation is inhibitory while the sympathetic effect is acceleratory.

The next structure of importance in this specialized system is the atrioventricular (A-V) node located on the right side of the interatrial septum, below and slightly anterior to the opening of the coronary sinus and the thebesian valve This node of His and Aschoff, with fan-shaped head, is microscopically similar to the Keith-Flack node and forms the bulbous beginning of the atrioventricular (A-V) bundle. From this node there proceeds the atrioventricular or His bundle, a compact ensheathed cord of specialized fibers, which runs forward and downward in the right side of the interatrial septum for about 2 cm., to form the main conducting bridge between atrial and ventricular tissues. On reaching the membranous portion of the undefended space in the intraventricular septum, it divides and straddles the septum; the left portion, piercing the membrane and spreading out under the posterior aortic cusp, produces the broad, flattened left branch of the bundle, while the right branch extends without major subdivision to the anterior papillary muscle on the right. Secondary atrioventricular bridges especially posteriorly and on the right side have been demonstrated and called accessory bundles of Kent. These may occasionally be significant.

The gateway to the ventricle and the path descending from it are sometimes called after the discoverers, the Aschoff-His-Tawara node and bundle, but both are more properly called the atrioventricular node and bundle. The right and left bundle branches spread downward on the interventricular septum, branching profusely as they reach the bases of the papillary

muscles to form, just subendocardially, a dense, syncytial meshwork of specialized tissue extending throughout the ventricular cavity beneath the endocardium, and producing the so-called Purkinje fibers or arborizations of specialized tissue. It is because of this widespread anatomic system that prompt and complete excitation of the ventricular muscle is accomplished, and is only rarely interrupted by extensive subendocardial processes. Purkinje fibers extend radially into the scrolls of the myocardium.

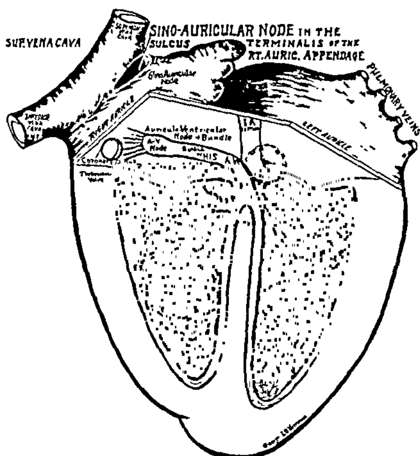


FIGURE 1 A diagrammatic representation of the special structures that control the origin and conduction of the impulses which regulate the cardiac mechanism

Some Physiologic Considerations: The normal physiology of the genesis and propagation of the excitatory impulse is most intriguing, although still far from being fully understood. A theoretical consideration of the important process must now suffice. The cell may be pictured as a minute mass of protoplasm, separated from the surrounding tissue fluid by the exceedingly thin membrane covering its surface. On the outer surface of this membrane, positively charged ions are more numerous, while on its inner surface, negatively charged ions are in preponderance. The attraction between these unlike ions creates an electric stress, but ionic intermingling

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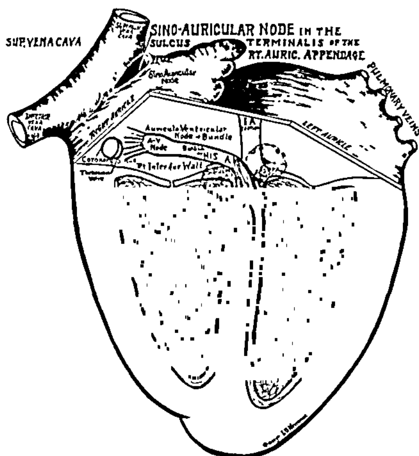


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is prevented by the temporary impermeability of the membrane. The metabolism of the resting cell supplies the energy required for maintenance of this unstable condition and for its subsequent periodic suspension.

In case of the cells of the nodal tissues, this state of dynamic equilibrium is a momentary one. Gradually, during diastole, the electric stress increases, or the resistance of the membrane decreases, until abruptly the membrane breaks down and loses its relatively impermeable state. Associated with this breakdown, a fall occurs in the electrical potential of the cell surface, and chemical processes are initiated within the cell which lead, on the one hand, to contraction and, on the other hand, to restoration of the impermeable membrane with its electrical double layer. Before this restoration has gotten well under way, however, a local current begins to flow between the positive, inactive, adjoining cells and the negative, active cell—a current of such intensity that it initiates a breakdown of the surface of the inactive cells and this, in turn, leads to excitation of cells at increasing distances. Thus, the excitatory process spreads rapidly and radially from the specialized sinoatrial node or pacemaker and the phenomenon of conduction of the impulse and the inaugurated wave of contraction follows.

Arriving at the atrioventricular node, the impulse is slowed sufficiently to allow completion of the atrial systole and then passes through the A-V bundle to the ventricle. Thence it is propagated subendocardially through the right and left branches and spreads in the Purkinje network at the rate of about 4000 mm. per second; thence out through the heart muscle cells at one-tenth that rate, stimulating in order and almost simultaneously the heart muscle of both ventricles, with, as a result, a concerted bilateral ventricular contraction

A brief rest period or diastole then supervenes and the generating processes recur at the sinoatrial node. This rhythmic formation of impulses in the sinoatrial node takes place at varying rates. Under abnormal conditions, other irritable foci may supersede the node and act as pacemakers. The impulse spreading through the atrial muscle is rarely obstructed but, because of refractoriness of the A-V node, the narrowness of the gateway and the bridge and its vulnerability, conduction through the A-V node and the His bundle may be interrupted by relatively circumscribed, slight or gross cellular changes in these structures. Atrial and ventricular muscle cells frequently become hyperirritable and interrupt the regular rhythm by sudden, persistent discharges from minute abnormal foci in the specialized or nonspecialized tissue of the free-wall musculature. Tissues that have been slightly damaged, perhaps by under-nutrition or other injuries due to circulatory disturbances, or toxic changes from bacterial poison, give rise to abnormal foci. Each premature ectopic impulse or extrasystole usually spreads retrogradely and meets and extinguishes the oncoming normal impulse from the S-A node, thus producing a prolonged postectopic diastolic rest period.

Effects of Nervous Control: The atrial muscle, the sinoatrial node, the atrioventricular node, and perhaps also a larger part of the His bundle, are under the direct control of the cardioinhibitory fibers of the vagus, while the whole heart is under sympathetic influence. The rate of impulse forma-

tion is dependent in large measure upon these nervous influences or reflexes. Stimuli with vagotonic or sympathicotonic influences on the heart rate as postural changes, physical effects, metabolic states, drugs, and diseases give rise to external and internal stimuli as do also anoxia, arterial and venous blood pressure changes and specific reflexes. An increased vagus tone causes a slowing of impulse formation in the pacemaker or lowering of the rate of impulse formation in the sinoatrial node and reduces the heart rate below the normal standard level of seventy, thus producing *sinoatrial* or *sinus bradycardia.* Likewise, a removal of the vagus effect or stimulation of the sympathetic or accelerator nerves produces a rise in rate, speeds up the rate of impulse formation distinctly above the normal level of eighty-five, usually to more than 100 per minute, a condition which is spoken of as a *sinus tachycardia.* The vagus tone may fluctuate as a result of the respiratory waves in the blood pressure which effect a rhythmical waxing and waning of the heart action, a common irregularity, the so-called *sinus arrhythmia.* The normal youthful heart action slows with expiration and quickens with inspiration.

The presence of disease in other parts of the body, affecting directly or indirectly the vagus tone, accentuates these effects on the sinoatrial node or the pacemaker This is especially true, as will be detailed presently, of diseases of the thyroid gland, the brain, the general nervous system, the psyche, or the gastrointestinal canal The impulse formation in the sinoatrial node may be entirely suppressed momentarily by extreme vagotonia, producing a *sinoatrial standstill* or *block* in rare instances. Pathologic changes in the tissues about the node are quite likely to be necessary for the production of this disturbance. True sinoatrial block is, therefore, probably of some significance.

Although the sinoatrial node usually dominates the mechanism as the pacemaker, other foci, in atrial, junctional or ventricular, specialized or unspecialized tissues, occasionally become more labile or irritable as a result of temporary nervous, mechanical, circulatory, nutritional, physical, or chemical changes and give rise to premature discharge of impulses. These then spread in all possible directions, wherever paths are open in the muscle or specialized tissue, and stimulate the heart muscle cells to *premature contractions*, extrasystoles or ectopic beats The resulting disturbance of initiation or propagation of the next regularly placed sinus impulse results in the postectopic pause

Under normal conditions, the wave of excitation originating in the sinoatrial node spreads fan-wise through the atrial musculature, activating it and then dying out An ectopic focus of rapid rate or a circus mechanism may supersede the pacemaker as a result of certain atrial myocardial changes producing *paroxysmal tachycardias* with *atrial, junctional* or *nodal* or *ventricular* foci or *atrial* flutter or *atrial fibrillation.*

The propagation of the impulse or wave of excitation may be obstructed by disease in the A-V node or in the His bundle or a branch of the His bundle, resulting in various grades of *partial* to *complete A-V, right* or *left bundle branch block.*

DISTURBANCES OF PHYSIOLOGIC MECHANISMS OF THE HEART BEAT

Classification:

I. *Impulse Initiation Disturbances:*

A. NOMOTOPIC: Regular rhythms (homogenetic).

1. *Variation in the vagal and sympathetic nerve action* (regular).
   - (*a*) Sinoatrial or sinus tachycardia, abnormally rapid regular sinoatrial (or *sinus*) rhythm.
   - (*b*) Sinoatrial or sinus bradycardia, abnormally slow regular sinoatrial rhythm.
2. *Vagus arrhythmias* (irregular).
   - (*a*) Sinoatrial or sinus arrhythmia, phasic respiratory shift in vagus tone.
   - (*b*) Sinoatrial standstill, or sinus block.

B. ECTOPIC: Irregular rhythms (heterogenetic).

3. *Premature contractions*, rare, frequent, irregularly occurring, regularly recurring, quadrigeminy, trigeminy, bigeminy or coupling (irregular).
   - (*a*) Atrial (supraventricular).
   - (*b*) Junctional (nodal or atrioventricular). (Supraventricular.)
   - (*c*) Ventricular (right or left basal or apical). (Idioventricular.)
   - (*d*) Indeterminate origin.
4. *Paroxysmal tachycardia* (regular).
   - (*a*) Atrial (supraventricular).
   - (*b*) Junctional (nodal or atrioventricular) (supraventricular).
   - (*c*) Ventricular (right or left) (Idioventricular.)
   - (*d*) Indeterminate origin.
5. *Atrial flutter* (regular).
   - (*a*) Paroxysmal.
   - (*b*) Chronic.
6. *Atrial fibrillation* (irregular).
   - (*a*) Paroxysmal.
   - (*b*) Chronic.

II. *Disturbances in Propagation or Conduction of the Impulse: Heart Blocks*

1. *Sinoatrial standstill or sinus block* (irregular or regular).
2. *Atrioventricular heart block.*
   - (*a*) Latent A-V block: prolonged A-V conduction (regular).
   - (*b*) Partial A-V block varying or constant.
     - (1) Occasional dropped beat (irregular).
     - (2) Low grade A-V block 10-9 to 4-3.
     - (3) High grade 2-1, 3-1 to 4-1 and even 6-1 may be regular.
   - (*c*) Complete A-V block dissociation (usually regular, may be irregular).
     - (1) Temporary or transient.
     - (2) Chronic, permanent.
     - (3) *Bundle branch block* (regular), *Alternation* (pulsus alternans) (regular).

Clinical Types and Differentiation: The clinically recognizable types of disturbance of the cardiac mechanism should be had clearly in mind before beginning the discussion of each of the individual disturbances. It is most logical to classify the conditions on a physiologic basis, proceeding from the purely functional and definitely innocuous disturbances to those of increasing seriousness or significance and, finally, to those disturbances that in themselves mean heart disease. This classification of the various conditions does not easily lend itself to clinical differential diagnoses. It is, therefore, desirable to discuss the conditions in the way in which the diagnostic problems may present themselves.

Clinical Signs of Disorders of Heart Action: The heart beat may be fast or slow, regular or irregular, persistently in the same condition or changing from time to time from one condition to another. There are some conditions in which the rate is always fast, and others in which it is always slow. Some disturbances vary not one beat in minute-to-minute counts, others vary greatly in periodic counts; some are always regular, others always irregular; some are usually regular but occasionally irregular; others are usually irregular and occasionally regular. Grouping the disturbances according to these findings is the first step in differential diagnosis. The degree of the disturbance is quite important and this is determined by the careful full-minute count of the rate of the heart or apex beat counted with a stethoscope.

Differential Diagnosis: *A rapid, regular* heart action may be *sinus tachycardia, paroxysmal tachycardia,* or *atrial flutter. A slow, regular* mechanism may be *sinus bradycardia,* or *atrioventricular heart block,* either high grade, partial, or complete. *A rapid, irregular* heart action usually means *atrial fibrillation,* but may mean frequent *premature contractions, interrupted short paroxysms* of *tachycardia,* or *irregular blocking* in *atrial flutter.* A *slow irregular* mechanism may be a *digitalized atrial fibrillation* or one of the slow fibrillations of aged people, *partial heart block,* or a *normal bradycardia* interrupted by *premature contractions* or a *sinus arrhythmia.*

Now to proceed with further differentiation, it will be necessary to give some of the diagnostic characteristics of the commoner types of disturbances.

The *first and most important rule should be that any absolutely irregular heart action* that persists when the heart rate is increased to 120 per minute probably is atrial fibrillation. If this persists as the rate rises to 140, it is almost certain that the mechanism disturbance is atrial fibrillation. All other disturbances that produce irregularity disappear as the heart rate rises. The heart rate may be increased by slight exercise or by the use of amyl nitrite, nitroglycerin or atropine. In the presence of an absolute arrhythmia, a rise in the heart rate to 100, 120 or 140 is not usually accompanied by a similar rise in the pulse rate. Many of the ventricular contractions come at such short diastolic intervals and are consequently so feeble, and act upon such a small volume of blood, that they are not able to raise the blood pressure above that in the aorta. They consequently do not open the valve and, therefore, are not propagated to the periphery, and thus is produced the disturbance known as *pulsus deficit.*

Premature contractions coming early in diastole may also fail to open the aortic valve and, therefore, likewise result in a deficit in the peripheral pulse rate.

An irregular rhythm due to premature contractions that disappears on increasing the heart rate, returns as the heart rate drops, as does also the irregularity of partial heart block. In the case of heart block when the intermittency reappears in the pulse, auscultation of the apex also reveals complete silence during the pause. In the case of premature contractions, as the heart rate drops and the pauses occur in the pulse, there is nearly always *the audible sound of the premature beat early in the diastolic period* at the apex, whether or not the ectopic beat comes through to the carotid or the radial arteries

The waxing and waning of sinus arrhythmia, revealed on careful examination, is exaggerated by forced respiratory movements and is thus easily identified whenever present. It is rarely found unless the heart rate is well below 100 per minute.

When the heart rate doubles itself or increases by a definite multiple following exercise, amyl nitrite, or nitroglycerin, the presence of partial heart block is to be seriously considered. A coupling of beats may mean a rare 3:2 heart block, but it usually means a bigeminy, *viz.*, every other beat is premature and is followed by a long, postextrasystolic pause. A trigeminy may simulate a 4 3 block, as may a rare interpolated, premature contraction, in every other diastolic period.

A *slow, regular rhythm* at the rate of forty per minute usually means heart block but may, in rare instances, be a sinus bradycardia; in this latter condition there is a definite or slight rise in rate, according to the amount of exercise or amyl nitrite given. The rate does not increase by a multiple nor does it approximately double, as in the case of partial block. A rate below forty is practically always due to complete heart block. This condition is further suggested when there is little or no increase in rate following the exercise or amyl nitrite tests.

A *rapid, regular rhythm* at a rate of between 100 and 120 per minute is usually due to sinus tachycardia, especially if it is susceptible to vagus influence When the rate is between 120 and 180 per minute, atrial flutter is to be considered and is more likely to be present when vagus pressure brings about slowing that can be maintained for a few beats only. A rate between 180 and 240 suggests paroxysmal atrial, junctional, nodal, or ventricular tachycardia, especially when there is the characteristic sudden onset and offset of the tachycardia.

SINUS TACHYCARDIA (Simple Tachycardia)

Definition: Sinus tachycardia is a sustained increase in the heart rate beyond the normal limits for the individual.

The disturbance is the evidence of a transient or persistent decrease in the vagus tone or increase in sympathetic activity, a change such that the rate of impulse formation in the sinoatrial node is increased, usually without any other disturbance in the mechanism, in the origin or the propagation of the impulse. As a rule, a persistent rate above ninety, and certainly

one above 100 beats per minute in an adult with an otherwise normal mechanism, should be considered sinus tachycardia. In children, especially infants, the normal rate is higher. The fact that at birth and during early infancy the rate is 130 to 146, at two years 120, at four years 110, at eight years ninety to ninety-eight, in the adolescent of fifteen years between eighty and ninety, and in the normal adult seventy-two to seventy-eight per minute on the average, makes a sliding scale necessary. Age must be an important consideration in the establishment of a natural normal heart rate.

Temporary or Transient Sinus Tachycardia: This is the commonest change of cardiac mechanism, and it occurs often with the slightest provocation and persists from a few minutes to a few hours. The heart rate rises at the end of the day and in changes from lying to sitting and from sitting to standing positions.

Tachycardia appears in perfectly normal individuals as a result of emotion, fear, eating, exertion, physical stimuli as heat, humidity, loud sounds, high altitude, low oxygen pressure, anoxia, anemia, deep inspiration, alkalosis, acidosis, fall in blood pressure, rise in pulse pressure, rise in venous pressure, and nervous reactions, neurocirculatory asthenia and nervous excitement with sympathetic stimulation; females after menstruation, in pregnancy, and in old age have high pulse rates from unknown psychogenic causes. Drugs, such as alcohol, atropine, Apresoline, ephedrine, epinephrine, cocaine, nitrites, thyroid extract, tobacco and caffeine, also increase the heart rate. The normal response to exercise is an increase in the heart rate resulting from a decrease of vagus together with an increase of accelerator tone. In exercise these changes are a response to increased venous return and to changes in the blood, possibly including slight relative oxygen want, the accumulation of acid metabolites of muscular activity, and augmented epinephrine output. The increased demand for oxygen in all tissues of the body, including the heart itself, must be supplied by an increase in circulation. In the ordinary tolerance test of exercise the heart rate will rise from twenty to forty beats as a result of mild exertion, but there is always a fall to the normal level within two minutes.

Etiology: The factors concerned in sinus tachycardia are various, and no one pathologic state is responsible. As a rule, the pathogenesis depends merely upon a functional imbalance between the effects of the vagus and the sympathetic or accelerator nerves. Fever of infectious disease results in a rise of seven beats per minute per degree of fever in most diseases except typhoid fever, hepatitis with jaundice and meningitis with increased intracranial pressure. Hyperthyroidism is responsible for a most severe and yet curable form of this disorder. Heart failure, active endocarditis or rheumatic carditis or myocardial infarction may cause intractable sinus tachycardia in most instances.

Symptoms: The symptoms of the condition are usually characteristic and by no means always give rise to the complaint of rapid heart action, although slight palpitation may have been noticed.

Diagnosis: If there is any doubt as to the diagnosis, electrocardiographic studies should be employed if available. This method of precision will show

a perfectly typical normal mechanism with sequential P waves and narrow QRS-T complexes with shorter diastolic or T-P intervals consequent upon the increase in rate.

Emotional, psychic, or psychogenic factors may increase the heart rate and maintain it at a high level for shorter or longer periods of time. This is especially true in neurotic patients with either neurocirculatory asthenia or postinfectious vagus lability, who may run a simple tachycardia for shorter or longer periods of time. Even in these, the pulse rate drops to normal, especially during sleep. Anxiety neuroses and neurasthenia show, as part and parcel of their clinical manifestations, a distinct imbalance in the sympathetic or involuntary vegetative nervous system.

Drugs that usually affect the heart rate are amyl nitrite, nitroglycerin, atropine, quinidine, epinephrine, ephedrine, and nicotine. Amyl nitrite effects a reduction in vagus tone as a secondary change due to the reduction of blood pressure. Atropine paralyzes vagus endings peripherally, as *does quinidine to a less extent. Epinephrine and ephedrine primarily stimulate* accelerators. Nicotine in excessive doses will have a similar effect, while in smaller doses or early poisoning, the opposite or vagotonic effect is predominant. The transitory or more persistently increased heart rate, beginning insidiously and ending in the same fashion, may be recurrent when there is a return of the exciting factors.

A prolongation of the period of rapid heart rate, that is a persistence of the sinus tachycardia, leads to the suspicion of a more serious disturbance, such as a postfebrile or infectious injury of the myocardium, especially when the heart rate remains over 100, with the patient under basal conditions Low-grade, chronic, focal infections of the teeth, tonsils, accessory sinuses, lungs, the prostate, cervix, gallbladder, and, more seriously, in the heart itself may produce no pain and very little rise in temperature but may be the source of trouble. Febrile reactions from other acute infections, with a few rare exceptions, will produce a rise of from seven to nine beats for each degree of fever.

Tuberculosis is especially prone to produce a high rate except in rare instances, where it involves the basal meninges and secondarily stimulates the vagus. Typhoid fever is characteristically accompanied by a relatively slow heart rate. Chronic pelvic inflammatory diseases are often subfebrile, yet often present a tachycardia. Influenzal and other virus infections may damage the heart to such an extent that the tachycardia persists and other evidences of myocardial damage appear sooner or later.

Among the metabolic disturbances, obesity apparently tends to increase the heart rate, while the outstanding *condition of thyrotoxicosis* or exophthalmic goiter characteristically gives a considerable rise in heart rate that is roughly proportional to, or is a rough index of, the degree of increase in the metabolic rate.

The disturbances in blood volume or shifts in blood mass, as in surgical hemorrhage and shock, or as a result of ether anesthesia, at first produce a distinct tachycardia.

Sinus tachycardia is to be differentiated from the other types of rapid heart beat in which the point of origin and the character of the impulse

formation, that is the mechanism of the beat, are abnormal. In the latter conditions the changes are primarily in the heart, while in sinus tachycardia the causes are usually extracardiac.

Differential Diagnosis: *Clinical Typing of Tachycardias:* Differential diagnosis is a simple matter in most instances because of the presence of definite or easily determined etiologic factors in the history of the case. The insidious onset and the gradual offset are of similar type and character. Stimulation of the carotid sinus by pressure at the bifurcation against the transverse process of the cervical vertebrae usually results in a perceptible slowing, causing the rate to vary from minute to minute, especially during these maneuvers Atrial flutter with 2:1 block gives a perfectly regular rapid heart action of 140 to 180 per minute. Under such conditions the more or less characteristic susceptibility of the A-V conduction path to a temporary increase in block produced by carotid sinus stimulation is usually sufficient for differentiation; the rate goes back to the previous rate even with continuance of the stimulus.

Paroxysmal tachycardias, especially those of atrial and nodal origin, present no etiologic factors The abrupt onset and the abrupt offset characterize them. In half the cases of paroxysmal *atrial tachycardia*, carotid pressure has no effect whatsoever, no altering of the rate from minute to minute. In the other half of the cases, however, carotid pressure or any other form of vagus stimulation will stop the paroxysms, the high rate of 160 to 260 dropping to an absolutely normal rate of seventy to ninety beats per minute. The patient during a paroxysm of atrial tachycardia is usually not very much distressed and certainly not to the extent expected at such a high heart rate. Paroxysmal tachycardias are common in patients with accelerated A-V conduction (the Wilson-Wolff-Parkinson-White syndrome).

Nodal or *junctional tachycardias* are usually somewhat less influenced by carotid pressure than the susceptible atrial tachycardias and the atrial flutters, but are usually more affected than the refractory half of atrial tachycardias

In *ventricular tachycardia* there is usually a slight irregularity of five to six beats noted in minute-to-minute counts. The rate of the ventricular tachycardia varies more than the ordinary two beats per minute. Usually there is also a history of some severe precipitating factor, frequently vascular disease of the coronary system with or without cardiac infarction due to coronary thrombosis, the latter often with a secondary pericardial friction rub and frequently also with pulmonary edema with accompanying frothy blood-tinged sputum. Further evidence of vascular damage is usually to be found, *e.g.*, a reverberating aortic second sound and a systolic murmur suggesting coronary sclerosis. The ventricular pacemaker is usually below the level in the conduction system at which the cardiac nerves are effective and, therefore, there is no response on the carotid sinus pressure, exertion, exercise, change in position, or amyl nitrite.

Pseudoventricular tachycardia and pseudoventricular fibrillation occur frequently in patients with accelerated A-V conduction (W.-W.-P.-W. syndrome). Atrial tachycardia and atrial fibrillation are conducted rapidly

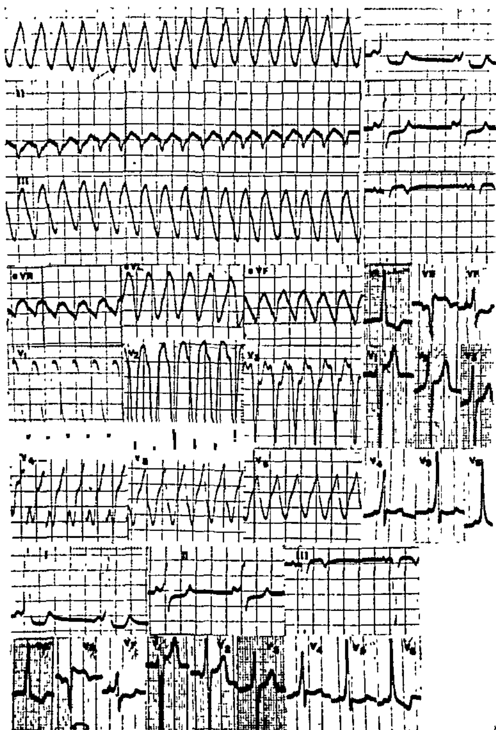


FIGURE 2. Paroxysmal pseudoventricular tachycardia which represents paroxysmal atrial tachycardia with accelerated A-V conduction or the W.-W.-P.-W. syndrome with short P-R interval and Delta waves shown in the electrocardiograms on the right.

through the accessory bundle (Kent) as a pseudo bundle branch block. (See Figures 2 and 3.)

Prognosis: Sinus tachycardia, especially the transient type, is of no serious significance, for it is a normal physiologic response in otherwise normal individuals Persistent sinus tachycardia is usually a part of a definite clinical syndrome and its prognosis depends upon that of the underlying condition. Under such circumstances the cause may be entirely

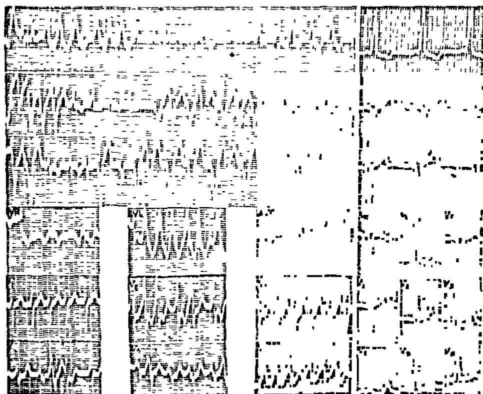


FIGURE 3 Paroxysmal pseudoventricular fibrillation which represents paroxysmal atrial fibrillation in a thirty-eight-year-old patient with accelerated A-V conduction or the W-W-P W syndrome with the short P-R interval and the Delta waves shown in the electrocardiograms on the right

extracardial, and in itself merely suggests the presence of myocardial damage. It is, therefore, not a reliable sign of heart disease. In the overly obese individual it may be taken as an indication for prophylactic weight reduction and for correction of any other metabolic disturbances.

Sinus tachycardia in one with edema in the dependent parts, dyspnea and orthopnea, and some cardiac enlargement, primarily dilatation, is of grave significance and indicates, along with the other signs, serious myocardial damage even in the absence of murmurs The presence of a sinus tachycardia and very loud murmurs suggests cardiac valvular disease. The absence of extracardiac disturbances that produce high rate leads to the suspicion of the frequent secondary infection of heart valves. This is usually due to hemolytic streptococci (*viridans*) or an exacerbation of acute

rheumatic endocarditis. Persistence of the high rate under these conditions indicates continued activity of the process. Postfebrile sinus tachycardia, as encountered in typhoid fever, usually suggests that the heart muscle has been damaged, and the length of time it persists is a rough indication of the amount of damage done. In typhoid fever the myocardial damage consists of hyaline degeneration without exudation, so that it is practically always completely healed without any permanent defect or disturbance.

Treatment: In sinus tachycardia this is, of course, directed toward the cause. When the latter is eliminated, the disturbance usually subsides and no especial specific treatment of the tachycardia is necessary. In a patient who presents reliable signs of cardiac damage, or even when these signs are not absolutely conclusive, there is good reason to suspect cardiac damage from previous infection or other causative agents. It is safest to try *rest in bed* with *passive exercise* until a normal rate is established, which should never take more than three or four weeks. Later under a short regimen of *exercises of gradually increasing intensity*, the patient is allowed to assume the upright position for longer and longer periods and slowly re-educates the heart muscle to the point where it will assume its burden without the abnormal increase in rate. I have occasionally digitalized such patients to the point of producing atrial fibrillation and then controlled the ventricular rate by maintaining digitalization. Neurosurgeons have reported successful interruption of intractable tachycardia by bilateral sympathectomy of the third, fourth, and fifth dorsal ganglia. In tachycardia of *psychogenic origin* or of distinct, definite *imbalance in the vegetative nervous system*, the use of *vagus-stimulating* drugs, such as *pilocarpine, acetyl choline*, has been advocated by the French. Reserpine, 0.25 mg. (1/250 grain), every three hours is most effective.

SINUS BRADYCARDIA (Simple Bradycardia)

Definition: Sinus bradycardia means a decrease in the heart rate below the normal for the individual with respect especially to age. It is the evidence of a temporary, transient, persistent, or permanent increase in vagus tone, whereby the rate of impulse formation in the sinoauricular node is decreased without any other disturbance in the mechanism of the origin or propagation of the excitatory impulse. As a rule, any heart rate below seventy beats per minute in a child or young adult with an otherwise normal mechanism may be said to present sinus bradycardia. The condition is considerably less frequent than its counterpart which has just been described, and may be either transient or persistent.

Etiology: The etiologic factors range from normal physical adaptation to serious central nervous system disturbances: Females before or during menses and in labor; males, especially athletes, show slow pulses. Years of heavy physical work and acclimatization to high altitude, cold, exposure, rise in blood pressure and asphyxia, changing bodily position from standing to sitting to lying down, deep expiration, deep sleep, arising, starvation, sudden carotid sinus pressure stimulation, emotion, intra-

cranial pressure rise and decreased pulse pressure usually produce bradycardia in normal hearts. Athletes in training are prone to have a slow heart rate. Among the general run of normal individuals it is not uncommon. The so-called vagotonic individuals will also present other evidences of increased vagus tone, especially with resulting mechanism disturbances in the gastrointestinal canal. Many normal individuals kept at basal conditions over extended periods of time will be found while at rest in bed to have a heart rate between fifty and sixty beats per minute. Starvation augments the slowing effect of rest on the heart rate. *Symptoms* rarely result from sinus *bradycardia* unless other factors are at play. Reflex or direct vagus stimulation will cause a decrease in the heart rate. Atropine may be used to eliminate entirely whatever vagus effect may be present and thus identify the slowing in the sinoatrial node or in the heart muscle itself after 1.2 mg. (1/50 grain).

Fainting attacks in individuals with slow pulses are usually vagal in origin. In unusually susceptible vagotonics, syncopal attacks may be precipitated by slight emotional disturbances. Some individuals are so susceptible that slight stroking of the neck by the barber in massage after shaving, or the drawing together of the coat collar by the fond wife as she bids her husband farewell may precipitate the syncopal attack.

In typhoid fever and in convalescence from diphtheria, cholecystitis and infectious hepatitis, jaundice, and occasionally from influenza and other acute febrile conditions, patients often present a distinct decrease in the pulse rate. Sudden rise in blood pressure may cause a bradycardia by reflex vagus stimulation from the carotid sinus. This is especially marked as the outstanding part of the Brannon syndrome during the diagnostic closure test of arteriovenous aneurysm. Women in parturition, after prolonged labor, nervous and physical exhaustion, and fatigue, may have a slow pulse and heart rate. Anoxemia seems to predispose in sinus bradycardia.

Certain vagotonic drugs, especially pro- or neostigmine (Prostigmin), nicotine, Pituitrin, potassium, digitalis, reserpine, protoveratrine, ephedrine, carbon dioxide, nitrous oxide, ergotamine, quinidine and quinine, Mecholyl, and pilocarpine, and occasionally physostigmine, may effect a slowing of the pulse, but morphine and digitalis rarely have this effect in the presence of a sinus mechanism.

Increased intracranial pressure from a tumor or the accumulation of exudate in the basal meninges may produce persistent bradycardia. Jaundice appears to produce a characteristic sinus bradycardia, slowing the heart either through central nervous effects or more probably by direct depressing action on the sinoatrial node. Slowing of the heart rate may result from circulatory changes in the region of the node, a not uncommon event in patients with coronary ischemic heart disease usually after the blood pressure has fallen The pulse is not slow when hypertension is acute, as apparently it is in the paroxysmal type. Myxedema, atherosclerosis, Cushing's syndrome and pheochromocytoma present usually a slow heart rate. The etiologic factors or causes and the pathology may be quite varied

since there are no specific local lesions so far as is known. The condition is usually asymptomatic but, in the aged, and especially in the presence of cerebral arteriosclerosis and a low blood pressure, giddiness, vertigo, and, in the more severe cases, syncope may result as complicating symptoms.

Diagnosis: Slow heart action may be produced by conditions other than functional or reflex sympathetic nervous influences. Organic lesion bradycardias are of much more serious moment than sinus bradycardia. There may be partial or complete atrioventricular heart block with slow idioventricular rhythm in the latter that must be differentiated. Characteristically, in sinus bradycardia the effects of the vagus and accelerator nerves are still present and the usual response may be elicited, *i.e.*, a gradually increasing rate after exertion or atropinization. In partial heart block the response usually results in an increased rate as a direct multiple of the previous rate, *i e*, a doubling if 2:1 block is present and an increase by a quarter in a 4·3 block. In complete block there is usually little, if any, response to exertion except, perhaps, in a child with rheumatic pancarditis. The rate in partial block is usually slightly higher than that found when a complete block is present. When there is absolute dissociation, the idioventricular rate of forty or below is usually present, except when this dissociation has been induced by digitalis intoxication, under which circumstances the rate may be as high as sixty with a regular independent idioventricular rhythm

In the partial heart block, at the time of the pause in the rhythm at the wrist, there is usually complete silence at the apex. It is essential to check this carefully, for frequently every alternate beat is an early premature contraction with insufficient pressure to open the aortic cusp, while every other or normal beat overcomes aortic pressure, producing a slow, regular rhythm. This type of premature contraction, like other types, usually disappears on exertion and the pulse rate will be doubled. It is, therefore. absolutely essential to auscultate the apex carefully in determining whether or not the slow pulse is due to a sinus bradycardia, a heart block, or a bigeminy with very early and weak ectopics. Electrocardiograms must again be the final court of appeal Sinus bradycardia is the slowed normal mechanism in which the P-R interval may be at the maximum normal *and the T-P interval greatly increased.*

Prognosis: This depends upon the precipitating factor. Usually sinus bradycardia is totally innocuous. It may, however, occasionally cause vertigo or syncope and be present in heart disease and even along with *congestive failure in rare instances.*

Treatment: This likewise must be guided according to the etiologic factor that is present. Where a definite etiology is demonstrable, steps should be taken to remove the disturbance. Usually the slow heart in itself causes no symptoms and no interference is called for. When the vagus irritability is so great as to cause syncopal attacks, even after the removal of exciting factors such as nicotine or reserpine, *tincture of belladonna* in 1-cc. (16 minims) doses, *atropine sulfate* up to 1 mg. (1/65 grain), or *homatropine bromethylate* up to 6.5 mg. (1/10 grain) is indicated in daily rationed doses.

SINUS ARRHYTHMIA

(Respiratory Vagus or Phasic Arrhythmia)

Definition: This most benign irregularity is due to rhythmically, regularly recurring, and alternating periods of gradual slowing down and speeding up of the impulse formation within the sinoatrial node and of the heart rate.

Etiology: The vagus nerve governs the rate of impulse formation. The vagus tone may fluctuate with the events of the respiratory cycle just as do the rhythmic variations in blood pressure; fluctuations follow the rise and fall of the irritability of the respiratory center. In the youthful heart, especially with deep inspiration, the vagus tone decreases and the heart rate quickens, while during expiration the reverse takes place and the heart rate slows. There are no symptoms produced by this regular irregularity, a waxing and waning of the rate of the heart. In some instances the respiratory effects may be just exactly the opposite, in which case this disturbance is called paradoxical. Occasionally there is no relation to respiration whatsoever, and an occasional long diastolic pause may be recorded without any previous or subsequent quickening. This is the type that may occasionally be associated with sinoatrial standstill

All of the types depend upon rhythmic changes in the vagus tone. The condition, therefore, usually is of physiologic significance in youth and in the aged. It occurs less commonly after adolescence or in adult life, until the increased vagus tone of advancing age or early senility comes into play. Nervous or general irritability greatly exaggerates the disturbance. Increasing the heart rate by slight exercise or the administration of amyl nitrite or atropine abolishes it and it practically never persists when the heart rate is above 100. Digitalis intoxication may be the causative factor in otherwise normally nonvagotonic individuals

In the rarer cases of sinus arrhythmia in which the patients do not respond with a rise to normal after the injection of atropine, thoughts must be directed to the possibility of heart block, a vagus neuritis or tumor, meningitis, or increased intracranial pressure from some grave intracranial disease. It may be present occasionally in an adult who presents other signs of cardiac failure. Sinus arrhythmia, therefore, cannot be taken as an absolute sign of a normal heart in spite of Mackenzie's dictum. Sinus arrhythmia rarely produces any symptoms except in the overly nervous and sensitive individual who is disturbed and worried by the irregular palpitation.

Diagnosis: The disturbance is one of infancy, childhood, adolescence, and senility. The frequency with which the condition is mistaken for some serious arrhythmia, such as atrial fibrillation, makes its recognition of considerable significance. Chief among the diagnostic signs is the fact that the irregularity disappears when the heart rate rises to 100 or above in response to exercise, amyl nitrite, or atropine. Slow deep inspirations and expirations, especially when forced, increase the respiratory arrhythmia. This reaction is quite characteristic, since none of the other irregularities is so characteristically affected, although premature contractions are often

precipitated by such maneuvers, they appear quite irregularly and show no cyclic tendency. Since atrial fibrillation rarely presents this characteristic phasic waxing and waning, and the irregularity is exaggerated by increasing the heart rate, the differentiation should not be at all difficult.

In the most exaggerated form of sinus irregularity there is occasionally complete sinoatrial standstill or sinoatrial block, and A-V heart block may be suspected. This is ruled out with difficulty, since the dropping out of the complete A-V cycle and the failure of a ventricular response alone have the same peripheral effects. When, however, the long interval comes at the end of expiration, and there is a gradual slowing up to the point of the dropped beat, followed by a gradual speeding up after the dropped beat, it is quite probable that a vagus effect is being dealt with, especially if the irregularity is abolished by mild exercise. Here, again, the electrocardiographic method alone will absolutely determine the state of affairs, as it is the only means by which a diagnosis of sinoatrial standstill can be made.

The "P" as well as QRS-T and the "a" along with the "c" and "v" waves of the jugular venous pulse are dropped. The electrocardiograms are generally characterized by a gradual lengthening of the diastolic period, *i.e.*, of the T-P interval, up to the longest one, and a gradual decrease to the shortest one. The P-QRS-T waves are always in normal array.

Prognosis: This is usually excellent but depends, of course, upon the age of the individual and the other accompanying cardiac findings. In the infant, child, or adolescent, sinus arrhythmia is a normal physiologic phenomenon; but in an adult, especially after middle age, it may be of some pathologic significance.

Treatment: This is rarely required for the condition itself. *Reassurance* suffices to allay undue anxiety. In the nervous patient *sedatives* may be of some value in suppressing any imaginary distress of this slight disturbance.

ECTOPIC REGULAR RHYTHMS

Abnormally increasing vagus tone may cause ectopic regular rhythms with slight, if any, changes in rate by a shifting of the pacemaker, apparently from the head to the tail of the sinoatrial node, or to lower levels in the specialized tissue. *If the increase in tone is sudden and temporary,* sinoatrial standstill is the result. If, however, the increase is persistent, a lower center must take up the function of the pacemaker. This disturbance is then simple and its presence is usually of nervous or functional origin.

The ectopic rhythm may be nodal or junctional, *i.e.*, with the pacemaker in the A-V node or in the junctional tissues, both of which are supraventricular foci. In rare instances the inhibition of impulse formation may also include the A-V node and bundle, so that an idioventricular rhythm may actually arise. Usually this occurs only in the presence of distinct pathology in the conduction tissues. When the pacemaker is displaced to the lower centers, the cardiac rate is usually definitely decreased; and the lower the level of the new pacemaker in the junctional tissues, the slower the rate will be. The rhythms of low junctional, and especially of ventricular, origin are regular and are quite uninfluenced by the vagus nerve effects.

ATRIOVENTRICULAR RHYTHM

(Nodal, Junctional, Auriculoventricular, or A-V Rhythm)

Definition: An A-V rhythm, *with generally a moderately slow rate, is* one in which the A-V node or bundle of His acts as pacemaker of the heart This occurs usually because of depression, of functional, nervous or pathologic organic origin, of the higher, normally more rhythmic, sinoatrial node or pacemaker. The condition is recognized usually and differentiated absolutely only in the electrocardiogram. Giant "a c" waves in the jugular pulse are strongly suggestive of A-V rhythm.

The impulse discharged from the ectopic pacemaker in A-V rhythm necessarily takes an abnormal or retrograde course to and through the atria and at the same time speeds on to the ventricles. Thus the atria may just precede the ventricles or all chambers may contract nearly simultaneously, or the ventricles may actually contract ahead of the atria. The type of A-V rhythm depends chiefly upon the location of the pacemaker. The varieties electrocardiographically recorded are: Type I, where the P-R interval is greatly shortened; Type II, where there is no P-R interval; Type III, where there is actually an R-P interval; Type IV, where there is a gradual shifting from Type I to Type III. In the first type, the pacemaker is presumably located in the extreme upper part of the A-V node. Thus, both atria are retrogradely activated ahead of the ventricles, but, since the impulse starts from a point between the sinoatrial node and the ventricles, it arrives at the latter after a shorter than normal P-R interval. In the third type, the pacemaker is nearer the ventricles, which are consequently first to be excited, while in the second type the locus is intermediate. The explanation of Type IV cannot be given in a few words, but is probably rarely due to actual migration of the pacemaker from a higher to a lower position as was once believed. The types of nodal or A-V rhythm are of no special clinical significance inasmuch as they cannot be recognized or differentiated from nondelayed A-V conduction except by electrocardiographic means.

The condition is relatively uncommon. It was frequently reproduced in perfectly normal young individuals by F. N. Wilson through a combination of atropinization and carotid sinus pressure It appears after acute fevers and frequently in digitalization, sometimes in the presence of localized circulatory changes or myocardial disease, especially in the atrium in and about the sinoatrial node. The rhythmicity of the new lower center is less than that of the sinoatrial node.

Any one of the conditions previously mentioned as factors in the production of increased vagus tone may precipitate nodal rhythm by depressing the normal pacemaker. Adrenalin, aconitine, or pilocarpine are drugs that occasionally cause it. Excessive doses of nicotine and ether, especially with an anesthetic anoxemia, predispose to it Nodal rhythm of Type IV has been recorded following coronary infarction. Besides simple depression of the sinoatrial node, A-V rhythm may sometimes result from an abnormal increase in rhythmicity of the atrioventricular node, which then usurps the pacemaking function. The rate will then be about as high as that of the S-A node.

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much higher than the normal rate of impulse formation. The rapid succession of these ectopic impulses, each one of which seems to depend upon the preceding activity, constitutes paroxysmal tachycardia. A possible explanation of these disturbances can easily be visualized as a circus mechanism such as has been accepted as the initiating and maintaining mechanism in atrial flutter and fibrillation. In only half the cases is the abnormal focus in the atrium susceptible to the influences of the vagus nerves, and either a complete effect may be elicited or none whatever from stimulation of these cardiac nerves. When effective, as it is in half of the cases, carotid sinus stimulation completely suppresses the abnormal mechanism within one cardiac cycle. According to recent work, there is apparently a definite relationship between disturbances of the calcium-potassium ratio in the heart muscle, which is reflected to some extent in the blood serum, in patients with serious heterogenetic rhythm disturbances Magnesium, potassium, and calcium ions are normally in a balanced solution in the heart muscle cells. These considerations are of some practical significance in that the disturbances may be promptly and spectacularly affected in varying the concentrations of these ions by the therapeutic administration of relatively massive amounts of one by mouth or a much lower dosage intravenously.

EXTRASYSTOLIC ARRHYTHMIA, EXTRASYSTOLES, ECTOPICS, PREMATURE CONTRACTIONS OR SYSTOLES, INTERMITTENCY OF THE PULSE

Definition: Extrasystolic or ectopic arrhythmia is the most common irregularity of the heart beat. It results from the occurrence of premature contractions that arise or are initiated precipitously from foci in the heart muscle outside the sinoatrial node.

This, the commonest disorder of the heart action, is usually an irregular interruption of the normal regular rhythm. It may be the result of nervous, mechanical, or chemical stimuli, worry, or atmospheric conditions, especially increased temperature and humidity, digestive disturbances, distention, allergic intoxications, or toxemias of infections. Drugs, such as digitalis, caffeine, nicotine, barium chloride, calcium, aconitine, chloroform, ouabain, arsphenamine, ephedrine, and epinephrine, may be initiating factors in susceptible individuals

The local changes resulting from nervous, circulatory, or mechanical changes or influences usually produce no pathognomonic anatomic lesions that are demonstrable in even the most careful microscopic examination. There must be, of course, physical and chemical changes in the affected heart muscle cells. Consequently, physiochemical rearrangements in localized groups of heart muscle cells seem to be the best etiologic, anatomic, or physiologic explanation of the phenomena These may definitely be related to the potassium-calcium-magnesium content of the heart muscle cells.

The type of extrasystole depends upon the point of origin. The disturbances may originate either within or outside the specialized tissue, *i.e*, in atrial, junctional, or ventricular tissues, or heart muscle cells. These supersede the normal impulses and are generally followed by postextrasystolic

NORMAL | PATHOPHYSIOLOGY | ELECTROCARDIOGRAMS | DIAGNOSIS

LEFT VENT · LEFT ATRIUM · A V · NODE RIGHT ATRIUM · BUNDLE BRANCH · SEPTUM · PURKINJE APEX · RT VENT

PATH OPHYSIOLOGY

EXCITATION ARISES IN S-A IS PICKED UP BY A-V NODE TRANSMITTED THRU A-V BUNDLE THRU PURKINJE NETWORK VENTRICULAR MYOCARDIUM

EXCITATION ARISES DISTANT FROM S-A

IMPULSE ARISES NEAR S-A

IMPULSE ARISES AT A-V

IMPULSE ARISES IN RIGHT VENTRICLE

IMPULSE FROM LEFT VENTRICLE

IMPULSE TRAVELS IN A CIRCLE ABOUT S-A

IMPULSE BLOCKED AT A-V NOT ALL GOING TO VENTRICLES

SUDDEN START AND STOP 1 NORMAL MAY EQUAL 2 FAST BEATS

ENTIRE BEAT DROPPED

PROLONGED P-R OR NO Q-R-S NO VENTRICULAR BEATS, DEATH RESULTS

C-PROLONGED Q-R-S, T OPPOSITE TO Q-R-S
1 AND 2 PROLONGED Q-R-S
3 SMALL AMPLITUDE, NOTCHING LONG Q R-S

I ARRYTHMIAS
A. SINUS ARRYTHMIAS
B EXTRASYSTOLES
1 AURICULAR
FAR
NEAR
NODAL
2 VENTRICULAR
RIGHT
LEFT
NUMEROUS
C. AURICULAR FIBRILLATION
D. AURICULAR FLUTTER
E PAROX TACH
II HEART BLOCK
A S-A NODE
B A-V BUNDLE
1 PARTIAL
2 COMPLETE
C COMMON (BUNDLE)
1. RIGHT BRANCH
2 LEFT BRANCH
3 ARBORIZATION

pauses. The pauses are usually compensatory. Occasionally, when the premature contraction occurs in early diastole, interpolation results, *i.e.*, a premature ventricular beat is seen between two normal sequential responses to sinoatrial impulses. In this latter disturbance, both the interpolated beat and the normal systole which closely follows it are weak. The condition is not distinguishable from paired premature beats, except by the electrocardiograph.

Premature contractions that disturb the basic, regular rhythm may originate in a single focus or in multiple foci, may occur at quite irregular

or regular intervals, as every other beat producing bigeminy; every third beat, trigeminy; every fourth beat, quadrigeminy, etc. In atrial flutter and fibrillation, according to the traditional view, all the impulses are of atrial ectopic origin. These disturbances, however, may also be further complicated by accompanying ventricular premature contractions.

In atrial ectopics only the atrial muscle is invaded by the impulse in abnormal sequence; transmission through A-V node to the ventricles is along the normal pathway. Such ectopics are not followed by pauses sufficient to make the sum of the durations of the pre- and postextrasystolic cycles almost equal to two normal cycle lengths as is the case in ventricular ectopics. The atrial ectopic impulse touches off the sinoatrial node promptly, and the recovery of the latter immediately begins, is completed in the normal time, and the postectopic pause is accordingly short.

In the case of most junctional and practically all ventricular premature contractions, the impulse, traveling slowly backward, does not reach the atrium or sinoatrial node because it meets the oncoming sinoatrial impulse. Thus, both the latter impulse and the retrograde ectopic impulse are mutually extinguished. The compensatory pause of the ventricle is simply the time it must wait until arrival of the next sinoatrial impulse.

The mechanical efficiency of the premature contraction is in inverse proportion to its prematurity. The most premature beats, of course, come at a time when the ventricles are incompletely filled, the resulting contraction is feeble, and the pressure generated may be insufficient to open the aortic cusp; and, consequently, the pulse wave is not propagated in the systemic or the peripheral circulation. Thus, the cardiac energy is dissipated or wasted as no onward movement of the blood is effected. The peripheral blood pressure of the premature contraction is usually low, but that of the impulse following the pause is distinctly increased. When occurring late in diastole, the concomitant blood pressure rise is usually sufficient to open the aortic valve and allow the wave to spread into the periphery. But, at best, premature contractions are weaker and less efficient than normal beats and the more premature the more they decrease coronary flow.

Symptoms: *Most normal individuals are not conscious of the presence of an extrasystolic arrhythmia unless they palpate their own pulses.* Nervous, highstrung, hypersensitive individuals, however, have many subjective symptoms and they are conscious of every disturbance—the pause and the augmented beat following the premature contraction. They may experience transient giddiness, vertigo, weakness, and momentary syncope or distress, with a disagreeable, ill-defined, precordial or substernal sensation especially in the older patients.

The hypochondriac may have the symptoms in a much exaggerated form. To him it appears that the heart turns over, jerks, and twists, and often seemingly sends the wave through forcibly to the top of the head. The irregular palpitation is most noticeable when the patient lies down to rest at night. Posture plays some part in this and it is especially a factor if the patient is lying on his left side or has his ear on a pillow. However, the slowing of the heart incident to rest seems to be the most important initiating factor. Long, deep, sighing respirations with holding of the

NORMAL PATH

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syncope. When a ...

A nervous patient with ...
reminder ... dizziness and ...
persistent but transient ...
Irregular or regular ...
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badly damaged heart ...
the result of the ...

Diagnosis: The ...
test, namely, that ...
from exercise ...
the extrasystoles ...
to the neighborhood ...
The rule that ...
the rate of 120 ...
disappear when ...
arrhythmias.

years and have lived the full span of life with apparently little inconvenience. Persistence of the disturbance in an exaggerated form occurs after exercise or the Valsalva test, usually only in patients with other evidences of heart disease and the prognosis then depends upon the heart disease itself.

The prognosis does not seem to differ, whether the ectopic beats be of atrial, junctional, or ventricular origin, although the latter seems to disturb the mechanism the most. A multiplicity of the points of origin may well be of more serious moment in suggesting a more widespread circulatory disturbance. The rate at which the extrasystoles originate seems to be of little significance, nor does the frequency of appearance of the disturbance seem to have any particularly definite bearing on the ultimate prognosis. Atrial extrasystoles, however, seem at times to be forerunners of fibrillation and paroxysmal tachycardia.

Treatment: *Removal of* any possible *causative factors* should be the first consideration. Habitual excessive nicotine and caffeine intake should first be curtailed. If drugs are used, such as digitalis, aconitine, barium chloride, epinephrine, or quinidine, they should be temporarily suspended at the appearance of an extrasystolic arrhythmia. Gastric distention causing mechanical embarrassment should be corrected. Food to which the patient is allergic or sensitive should be eliminated. A sojourn in the mountains is desirable for those that are further embarrassed and oppressed by the hot, humid season in low altitudes.

Nervous individuals must be constantly reassured and instructed to *avoid excitement* and to take sedatives such as *bromides* or *barbitals. Mellaril* 10 mg. or *Atarax* 10 mg. (1 6 gr.) q 3 hours are most effective. An excessively acid urine calls for changing the reaction by the use of *alkalis* and this is sometimes followed by gratifying relief of an irregular palpitation. In some patients the use of *atropine* accomplishes the end; in others, the use of *digitalis* is efficacious. Application of the classical studies of the older physiologists on the effects of ions of potassium and calcium, along with those of sodium, upon the mammalian as well as the frog heart, may yield promising results Beginning with the work of Ringer, it was shown that, independent of osmotic pressure, a balanced solution of potassium, calcium, and sodium ions was necessary to maintain normal heart action.

Rothberger and Winterberg in 1911 corrected extrasystolic arrhythmias with potassium salts. *Potassium* deficiency is possibly a causative agent in extrasystolic arrhythmia of nervous, mechanical, or circulatory origin, but probably not when the irregularity is of toxic origin. In the latter, *calcium salts* are more effective, as they are in some paroxysms of persistent ectopic impulse formation.

These facts have been applied clinically by Sampson and Anderson, who found that *potassium iodide* or *acetate* administered by mouth in doses of 1 to 5 Gm. (15 to 75 grains) stopped the extrasystolic arrhythmia in half of their patients Wolfe and Bellet have stopped paroxysmal tachycardia by intravenous *calcium gluconate* administration. Katz and Elek have found papaverine, 0 4 to 0 6 Gm. (6 to 10 grains), most effective.

PAROXYSMAL TACHYCARDIA

Definition: Paroxysmal tachycardia consists of rapid, regular rhythm, of precipitate onset and equally sudden offset, originating in an abnormal or ectopic focus in the atrial, junctional tissues or the ventricles. Paroxysmal tachycardias may thus be regarded as due merely to a rapid succession of extrasystoles. As such, they depend on the same initiating factors. The theoretic reasons for the maintenance of this focus as the pacemaker have been touched upon in the preceding discussion concerning the genesis of extrasystolic arrhythmias. The idea that herein is another possibility of a circus mechanism has been suggested in some theoretic discussions. The mechanism begins sharply and stops abruptly, often with an atrial and a nodal or a ventricular ectopic beat. The rate rises from its normal level of about eighty to from 180 to 240 beats per minute and drops, within one beat, from the high rate to the previous normal rate of eighty, or whatever it may have been.

The types of paroxysmal tachycardia and the clinical manifestations and significance depend upon the locus of the mechanism disturbance. The ventricular type is by no means common and the junctional or nodal type is quite rare, while the atrial paroxysmal tachycardia is fairly frequent. The point of origin determines in some way the character of the attack or at least some of its characteristics. Most common is the simple *atrial* type. This is the type that occurs off and on, and lasts for short periods of minutes at first and gradually increases either in frequency or duration

Chronic sufferers have tolerated paroxysms for twenty to forty years. The few rare *junctional* paroxysmal tachycardias that have come under the author's care have lasted for long periods of time, weeks and up to eighteen months. In one such instance, the disturbance was observed to last for one and a half years; the patient was not observed after that time because he did not return for treatment. The most serious form is *ventricular* tachycardia which usually lasts for hours or parts of a day and occasionally for several days. It is generally accompanied by very pronounced symptoms of serious heart disease, especially coronary sclerosis, thrombosis, and cardiac infarction.

Paroxysmal tachycardia may, in rare instances, present a syndrome similar to that of cardiac infarction. There may be pain and collapse, fever, and leukocytosis; however, conclusive evidence of infarction is rarely present. If the latter symptoms are present in paroxysmal tachycardia, it is not usually possible to make a diagnosis. The electrocardiographic study may be very helpful, for it will determine the point of origin of the disturbance and give evidence of the conduction defects or changes that accompany cardiac infarction. In about two-thirds of the cases of paroxysmal ventricular tachycardia other evidences of cardiovascular disease are present.

Symptoms and Complications: There are no premonitory symptoms for any of the varieties of paroxysmal tachycardia. Usually the onset is very abrupt and without any recognizable initiating factor. Occasionally, at the inception of the disturbance, there is a sensation of a sudden cardiac pain. The patient may not be conscious of the rapid rate as palpitation if the

disturbance is regular, but again the overactivity may be quite disturbing and may be the patient's chief complaint. Occasionally vertigo, faintness, syncope, weakness, exhaustion, depression, smothering, epigastric fulness, nausea, and vomiting may develop. In some instances, and especially in the ventricular type of paroxysmal tachycardia, there may be pulmonary edema, frothy blood-tinged exudations, and expectoration of large amounts of pink-stained sputum.

During an attack, patients may exhibit much anxiety, pallor, then grayness and cyanosis, coldness, and clamminess. The neck vessels and the precordium throb rapidly and more or less violently. There is a rapid tic-tac embryocardia, but usually no murmurs or adventitious sounds are heard. The pulse is small, rapid, and regular. The heart beat remains regular and rapid between 180 and 220 per minute usually; occasionally it drops as low as 140 and rises as high as 240 at the extremes. In the atrial type, the rhythm is absolutely regular, as it is in the junctional or nodal type, but in the ventricular type of paroxysmal tachycardia, as pointed out by Levine, there is a slight irregularity revealed by the fact that there is a difference of a few beats between minute to minute counts.

Diagnosis: Paroxysmal tachycardia along with fever and leukocytosis in the presence of pain, necessitates a careful examination for the friction rub of a cardiac infarct. Paroxysmal tachycardia may often arise during the progress of an operation or shortly afterward and is diagnosed as acute cardiac dilatation. The true state of affairs should be recognized, for the good results of the operative procedures may be greatly jeopardized by the greatly decreased cardiac output, minute volume and total blood flow. Gangrene of a part may result as a complication of local hypotension.

The diagnosis must often be made from the history only, especially in the atrial type, which at times lasts for only a few minutes and stops *before a physician is reached and the opportunity for examination is* afforded. Here the suddenness of onset and offset, the regularity of the pulse and the equality of minute counts, together with a general lack of systemic disturbances due to the high heart rate suggest paroxysmal tachycardia of atrial origin. An unusual physical or emotional strain as the possible precipitating factor is substantiating evidence.

In about half of the patients with paroxysmal atrial tachycardia, stimulation of the vagus directly or reflexly by compression of the *carotid sinus* against the transverse processes of the cervical vertebrae causes a prompt cessation of the disturbance and a prompt drop back to a normal rate. If the rate does not drop, the maneuver has absolutely no effect whatever upon the mechanism. This contrasts with the result obtained in atrial flutter, for instance, which likewise may present a rapid regular rhythm, but which is distinctly influenced by vagus pressure. In atrial flutter, however, the vagus slowing or standstill is only temporary; the influence wanes even though stimulation is maintained by continued pressure on the carotid sinus. Occasionally the reflex slowing is not elicited in atrial flutter.

Paroxysmal atrial fibrillation presents absolutely irregular palpitation and heart action, but in the high grade type the characteristic rapid runs often simulate short paroxysms of regular mechanism. These, however, are

some shorter than even the unusually short attacks of paroxysmal tachycardia. The complete arrhythmia may be of precipitate or sudden onset, with a perfectly normal mechanism between the attacks. Paroxysmal sinus tachycardia usually has a lower level of rate and is usually somewhat more definitely affected by vagus pressure than is paroxysmal atrial tachycardia. Again, the electrocardiographic method is of considerable importance since the diagnosis can be made practically certain in this way. The analysis of the curve rarely presents any great difficulty of any sort.

Prognosis: This depends entirely upon the type of paroxysmal tachycardia that is present. Simple atrial paroxysmal tachycardia may be found in an otherwise perfectly normal heart. Aside from the occasional temporary distress, the patient is, as a rule, none the worse for the disturbance. Prophylaxis consists in avoiding the sudden stresses that initiate the attacks. Later on in life, with aging and increasing vagus tone, there may be in some patients a gradual decrease and a total disappearance of the attacks. In others, there may be an increase in the frequency and in the duration of the attacks. In the junctional or nodal type of paroxysmal tachycardia the outlook is less promising. The few cases that have been seen were persistent for a long period. Under such stress the heart is bound to weaken. Paroxysmal ventricular tachycardia is the most serious of the group, especially because of its frequent association with serious coronary ischemia. The associated heart conditions, therefore, determine in a large measure the prognosis of the mechanism change.

Treatment: The therapy of paroxysmal tachycardia depends upon the type. As stated before, in about half of the cases of *atrial tachycardia,* prolonged paroxysms may be stopped by exerting *pressure over* the *carotid sinus* and compressing it steadily against the cervical transverse processes on either side or by *ocular pressure* or other reflex vagus stimulation. The Valsalva and Müller respiratory experiments, *gagging and vomiting* and the *drinking of solutions in* various *unusual* ways or *positions,* may often bring about a cessation through indirect or reflex vagus action. In the Valsalva experiment, the rise in blood pressure stimulates the receptors of afferent fibers in the aorta (Marey's) and carotid sinus (Hering's reflex), and the impulses thus aroused, upon arrival at the medulla, enhance the activity of the vagoinhibitory center and thus inhibit the heart. The other procedures may increase vagus action in an analogous reflex manner. Sedatives as *barbiturates* or *morphine sulfate* often stop attacks.

In order to stop long attacks abruptly, various powerful drugs have been used. Constant electrocardiographic control is requisite in all intravenous therapy. *Neostigmine* (*Prostigmin*) in doses of 1 to 2 cc. of 1:4000 solution intravenously, or *acetyl-beta-methylcholine* (*Mecholyl*) in 0.02 to 0.04 Gm. (⅓ to ⅔ grain) doses subcutaneously are successful in 75 per cent of cases, particularly if followed by *carotid sinus* pressure.

If *digitalis* is not the cause, drugs, such as *Cedilanid D* in 4-cc. (1-dram) ampules of 0.8 mg. (1/80 grain or 2.4 cat units), or *Digoxin* in similar dosage, are the safest emergency intravenous cardiac tonics. *Acylanid* (acetyldigitoxin solution) 4 cc. ampule of 1 mg. (1/65 grain) intravenously will stop most severe paroxysms. Digitalis is especially indi-

cated if there are signs of myocardial insufficiency, and digitalis has not been the precipitating factor. *Strophanthosid* and *ouabain* are likewise considered effective, but are dangerous drugs in the presence of previous digitalization. A high rate of paroxysmal tachycardia may change to fatal ventricular fibrillation, fortunately an infrequent complication.

Neo-synephrine in 1 per cent solution in doses of 0.15 mg. to 0.8 mg. (1/40 to 1/80 grain) intravenously has stopped paroxysms of atrial and nodal tachycardia. The dose must be kept low to avoid dangerously high blood pressures.

Mephentermine sulfate (Wyamine sulfate), metaraminal bitartrate (Aramine bitartrate) and *methoxamine hydrochloride (Vasoxyl)*, preferably in doses of 10 to 20 mg. (1/6 to 1/3 grain) intramuscularly, or *levarterenol bitartrate (Levophed) 4 mg. (1/15 grain) in 500 cc. intra*venous drip in the presence of shock or low blood pressure, are most effective.

A 20 per cent solution of *magnesium sulfate* injected intravenously, slowly for the first 5 cc. (1¼ drams), then more rapidly 5 to 10 cc. (1¼ to 2½ drams), is usually an effective method. In one patient, 10 cc. of 25 per cent solution followed in six hours by 22 cc. of 25 per cent solution has been required to stop an attack refractory to all of the above mentioned inhibitors.

Quinidine lactate or *gluconate*, diluted in 500 cc. of 5 per cent glucose, may be given intravenously in doses of 0.5 to 0.6 Gm. in emergency situations, or as sulfate, orally, 0 3 to 0.6 Gm hourly until paroxysm stops or 3 to 6 Gm. have been given It is most effective in ventricular tachycardia.

Quinidine sulfate by mouth has been used successfully in some cases in doses of 0.2 or 0.5 Gm (3 or 7½ grains), the average dose being 0.3 Gm. (5 grains) every hour for eight doses. Quinidine by mouth every four to eight hours seems to prevent a recurrence of attacks in about two-thirds of the patients. Chloroquine or plasmoquin may be substituted for quinidine.

Procaine amide (Pronestyl), 250 to 350 mg. orally, is most effective and safe in ventricular tachycardia. It is also successful in some nodal and occasionally in supraventricular tachycardia.

Potassium salts, iodide, chloride, or *acetate*, administered by mouth, in doses of from 1 to 5 Gm., will often serve to decrease sharply the frequence of attacks of paroxysmal tachycardia. Intravenous administration of *potassium chloride* is safe up to 0.6 mEq./kg., up to 40 mEq. per one-half hour, for a 70 kilogram man. Orally 3 to 6 Gm. per day may be required.

Electrocardiographic monitoring of all intravenous drug therapy for cardiac mechanism disorders should be routinely practiced.

The *calcium ion* and its balance with *potassium* have been shown experimentally to have considerable effect and recently have prompted the prophylactic use of calcium by mouth for recurrent tachycardia.

Calcium lactate orally in doses of 1 Gm (15 grains), three times a day, in tablet form, should be used.

Calcium chloride or *gluconate*, intravenously, in doses of 10 to 20 cc. (2½ to 5 drams) of a 10 per cent solution making a total of from 1 to 2

Gm. (15 to 30 grains) of the drug, is effective but dangerous, and may be death-dealing in digitalized patients.

A fatality during the intravenous injection of 1 Gm. (15 grains) of quinine dihydrochloride, in a patient with junctional tachycardia, warrants caution in the use of powerful drugs in the presence of high heart rates.

In paroxysmal ventricular tachycardia, if the patient is not in shock, it is best to first try *potassium chloride* in doses of 1 Gm. (15 grains) repeated three times at hourly intervals. If this fails, oral *quinidine sulfate* is usually successful, but large doses may be required. If the situation is serious or the patient is vomiting but the blood pressure is sustained, *Pronestyl, procaine amide,* 250 to 750 mg. intravenously is a fairly safe and successful therapy. If the blood pressure drops and the patient approaches shock, *sympathomimetic amines* are in order. In such emergencies considerable success has been achieved by *norepinephrine* or *Levophed,* 4 mg. in 1000 ml. of 5 per cent glucose solution given intravenously at the rate of 2 cc. per minute under constant electrocardiographic and blood pressure observations.

ATRIAL FLUTTER (Auricular Flutter)

Definition: Atrial flutter is a disorder of atrial activity, characterized by rapid, regular, abnormal atrial contractions, and by ventricular systoles (usually half as many). The rate of the atrial contractions ranges from 220, or slightly less, to as much as 340 per minute. The average is usually about 300 per minute. The ventricular rate is commonly one-half the atrial rate because of the presence of 2:1 atrioventricular heart block; but at times it is slower or irregular because of greater or varying degrees of heart block. In some rare cases there is induced a release of heart block, and the ventricular rate is as rapid as the atrial rate (1:1 rhythm) if quinidine is given first.

Varieties: Atrial flutter may be *paroxysmal* or *chronic.* Most commonly it is paroxysmal, the disturbance lasting for a few minutes, hours, days, less often weeks, rarely for months or years.

Pathogenesis: According to Lewis (1920), atrial flutter results from a change in the physiologic condition of the atrial musculature which delays the rate at which the contraction passes through it. As a consequence, the wave of excitation and contraction, after traversing a part of the atrial musculature and returning to its point of origin, finds the latter no longer refractory, but irritable. In consequence, one contraction wave after another spreads along the same path in "circulatory rhythm." The path of the regular "circus contraction" is about the orifices of the great veins in the atria; and impulses radiating from the "circus contraction" spread to all parts of the atria and to the atrioventricular node. If the path of the "circus contraction" is shortened, its rate increases; and, if it exceeds 360 per minute, it becomes irregular. When rapid and irregular, the condition is atrial fibrillation. Between atrial flutter and fibrillation, there is a state which may be called "flutter-fibrillation" ("impure flutter," "coarse fibrillation"). Scherf and Prinzmetal, 1950, question the concept of circus mechanisms.

Clinically, atrial flutter may be considered as midway between paroxysmal atrial tachycardia and atrial fibrillation. However, the mechanism of atrial flutter differs entirely from that of paroxysmal atrial tachycardia, as evidenced by the electrocardiogram As a rule, the atrial rate of paroxysmal atrial tachycardia is 160 to 220 or at most 240 per minute, while, with but rare exceptions, the atrial rate in atrial flutter is over 240 up to 380 per minute, and in atrial fibrillation 380 to 650 per minute.

Etiology: Atrial flutter is not extremely common. It is quite possible, however, that short paroxysms are frequently overlooked or are mistaken for paroxysmal tachycardia. It is commonly found as a complication of *mitral stenosis, thyrotoxicosis, hypertension, or coronary disease; rare cases* occur in perfectly healthy individuals without any other evidence of heart disease. Nervous excitement, sudden effort, surgical operation, or trauma may be precipitating factors. It is found about three times more frequently among males than among females About three-fourths of the cases occur in individuals beyond the age of forty years.

Pathology: No characteristic pathology is associated with atrial flutter.

Symptoms and Complications: The most common symptom is *palpitation*, which may be so severe as to give rise to marked nervous excitement. When the ventricular rate is very rapid (240 to 300 per minute), dizziness, weakness, faintness, or actual syncope may result from impairment of circulatory efficiency. Symptoms of congestive failure may be coincident with, or may be induced by, atrial flutter of long duration. Congestive heart failure, atrial thrombosis, and embolism occur occasionally as complications, but are less frequent *than in atrial fibrillation*.

Diagnosis: Not uncommonly, an electrocardiogram is necessary to make certain the diagnosis of atrial flutter. However, the condition should be suspected in the presence of a rapid, regular heart rate, persisting in spite of rest, exercise, and, at times, drug therapy, particularly if there is other evidence of heart disease. Carotid sinus pressure characteristically slows ventricular rate momentarily in atrial flutter, but does not stop the circus rhythm, while its effect is all or none *in paroxysmal atrial tachycardia* Regularly recurring C waves or circuses at rates of 240 to 340 per minute with 2:1 atrioventricular block are electrocardiographic characteristics.

Prognosis: Atrial flutter is usually an annoying and more or less disabling condition, but it is seldom dangerous Often the paroxysm lasts only a few minutes, hours, or days, stopping as abruptly as it started; or, it may last for weeks or even years, finally stopping spontaneously or changing to *atrial fibrillation*.

Treatment: Short paroxysms of atrial flutter, lasting only a few minutes or several hours, require no treatment other than *reassurance* and *rest*. An *ice bag* to the precordium and mild sedatives, such as *barbiturates*, or tranquilizers may prove of benefit

When the paroxysm has lasted more than a few hours, *digitalis* should be given in doses of 0.2 Gm. (3 grains) of the powdered leaf, three or four *times daily, for several days, as indicated. If after several days the* ventricular rate has been reduced to normal but atrial flutter still persists, digitalis should be continued in daily maintenance dosage. At times, when

atrial flutter changes to fibrillation under digitalis therapy, stopping the administration of the drug is followed by the return of normal rhythm. When normal rhythm is restored, further use of digitalis is not necessary. In about half the cases, digitalis therapy alone is successful. In patients in which digitalis-produced fibrillation fails to revert to normal rhythm, with block and reentry persisting, the administration of *quinidine sulfate* 0.3 to 0.6 Gm. (5 to 10 grains) every hour for six to eight doses, by mouth, may prove successful.

It is safer to prevent 1:1 atrial flutter by preliminary digitalization. *Cedilanid D*, 0.8 to 1 6 mg. intravenously, is most often promptly successful. In atrial flutter with a slow circus rate, quinidine may be given the first trial, and then, if normal rhythm is not directly restored, the course of digitalization may be given Quinidine sulfate, or chloroquine or Plaquenil in doses of 0.2 Gm (3 grains), is given every hour for ten doses to stop flutter or fibrillation and two or three times a day to reduce the frequency of paroxysms.

Avoidance of fatigue, physical and mental overexertion, overeating, excessive use of alcohol, tea, coffee, and tobacco; and prevention of infections and congestive heart failure aid in the prevention of paroxysms of atrial flutter.

ATRIAL FIBRILLATION

(Auricular Fibrillation, Pulsus Irregularis Perpetuus; Absolute or Perpetual Arrhythmia; Delirium Cordis; Mitral Pulse)

Definition: Atrial fibrillation is a cardiac arrhythmia, characterized by absolute irregularity of ventricular action and complete absence of normal atrial systole Fundamentally, it is a disturbance of atrial origin, the walls of the atria being the seat of fine rapid fibrillary contractions to some of which the ventricles respond in an irregular manner.

Varieties: Atrial fibrillation may be: *paroxysmal* or *chronic*. It is usually the latter, and, when once established, it tends to persist unless treated vigorously.

Pathogenesis: The mechanism of atrial fibrillation is quite similar to that of atrial flutter, except that the "circus contraction" in atrial fibrillation is irregular and more rapid, being 600 to 900 per minute.

Etiology: Atrial fibrillation constitutes about half of the serious cases of persistent arrhythmia of the human heart. According to etiology, atrial fibrillation is commonly divided into (1) the rheumatic, and (2) the nonrheumatic (arteriosclerotic and miscellaneous) groups About 66 per cent of the cases are of rheumatic origin. About two-thirds of the cases of advanced mitral stenosis are complicated with atrial fibrillation. Atrial fibrillation is not infrequently associated with thyrotoxicosis. Comparatively rarely is it associated with syphilitic cardiovascular disease. Also, the combination of atrial fibrillation and angina pectoris is extremely rare, and subacute bacterial endocarditis and atrial fibrillation are rarely combined.

Occasionally atrial fibrillation occurs in otherwise perfectly healthy individuals without heart disease. It seems that there is possibly a nervous

hypersensitiveness which predisposes to the arrhythmia. At times, factors such as physical and mental overexertion, excessive use of tobacco, alcohol, tea and coffee, infectious diseases, trauma, and gas poisoning are responsible for the onset of paroxysmal or permanent atrial fibrillation. Males are affected about twice as frequently as females, possibly because of being subjected to greater strain. The average age of onset of atrial fibrillation due to rheumatic cardiovascular damage is thirty-nine years, while the average age of onset in the arteriosclerotic (nonrheumatic) group is at about fifty-nine years.

Pathology: No characteristic pathology is associated with atrial fibrillation.

Symptoms and Complications: Irregular rapid palpitation is the characteristic symptom of atrial fibrillation. It is most annoying at the onset of permanent fibrillation or during paroxysms. When permanent and properly treated, atrial fibrillation exists at times without symptoms. Occasionally, dyspnea and pain of various types are complaints, particularly when a marked psychic element is present, and after myocardial failure develops When the heart is very rapid, the individual may complain of weakness, dizziness, and faintness. In many cases, the ventricular (apex) rate is faster than the radial pulse rate, the difference being the "pulse deficit." The apex rate may be as high as 160 per minute, and the radial pulse rate as low as sixty. Under optimum digitalization, both rates may become seventy, the pulse deficit having disappeared. In every person with atrial fibrillation it is extremely important to record the apex heart rate as well as the radial pulse rate. The blood pressure in atrial fibrillation may be normal, high or low.

Heart failure forms the chief complication of atrial fibrillation. Thrombi form as a result of stagnation of the blood in the atria or in the veins of the lower extremities and pelvis, therefore, an often serious, and at times fatal, complication is *embolism* into the cerebral, splenic, renal, or peripheral circulation.

Diagnosis: A conspicuous arrhythmia that persists when the heart rate is increased to 140 per minute is atrial fibrillation. Other types of disturbance of the heart's rhythm vanish as the heart rate is elevated to 120 to 140 per minute. The rule may fail in rare instances of short paroxysms of atrial tachycardia and flutter.

Electrocardiography is of great value in confirming the diagnosis of atrial fibrillation. The typical electrocardiogram is characterized by total irregularity of ventricular complexes; an absence of P waves; the presence of small, rapid undulations (*f* waves); and, not infrequently, variations in the amplitude of the R waves and R-R interval from cycle to cycle.

Prognosis: In the absence of serious myocardial disease, atrial fibrillation of paroxysmal or chronic form may cause very little discomfort if the ventricular rate is kept within normal range. With digitalis or quinidine therapy, some individuals are able to enjoy active lives for twenty or more years. Because of the danger of myocardial failure, the tachycardia is more serious than the irregularity *per se.* According to Cookson, the expectation of life in atrial fibrillation is greater in the arteriosclerotic (nonrheumatic)

group than in the rheumatic group. In twenty-three rheumatic patients in whom the age of onset of fibrillation was between twelve and seventeen years, the average duration of life was ten months; while in sixteen patients in whom the age of onset was between twenty-eight and thirty-eight years, the average duration of life was six and one-half years. In very rare cases, death occurs suddenly, presumably due to ventricular fibrillation.

Treatment: *Absolute rest* and *full and maintained digitalization* are indicated in cases of atrial fibrillation with any tendency to pulsus deficit or congestive failure. Digitalization may be accomplished rapidly by intravenous administration of 1.2 to 1.6 mg. of *Cedilanid D*, or more slowly orally with *Acylanid, acetyl digitoxin*, 0.8 mg. immediately and 0.4 mg. four times a day dosage or by *digitalis D. L. pills*, 0.1 Gm., a total of 1.6 Gm. in 0.8 Gm., then 0.4 Gm. and 0.4 Gm. doses at eight hour intervals. (For the administration of digitalis, see also Chapter 17, *Digitalis*.) In persistent fibrillation the heart rate should be kept between sixty and seventy by daily maintenance doses of digitalis.

In the absence of serious myocardial disease, congestive failure, and embolism, *quinidine* or *chloroquine* may be administered. A paroxysm of atrial fibrillation which has been present for more than two or three hours can often be arrested with quinidine or chloroquine.

Oral digitalis is not prescribed in paroxysms of short duration because of its slower action and because it may prolong the attack. If quinidine proves ineffective, however, *Cedilanid D* is used, especially if congestive failure supervenes *Fagarine* (0.08 to 0.10 Gm. intramuscularly) has been used as an anti-arrhythmic drug with satisfactory results in atrial fibrillation and flutter but frequent toxic reactions have caused its discard.

Sedatives. Barbiturates in doses of 16, 32, or 65 mg. (¼, ½, 1 grain) a day prove useful in allaying restlessness. *Atarax* and other *tranquilizers*, such as *Melloril*, are helpful. An *icebag* locally is of value in relieving precordial discomfort. Rarely is *codeine sulfate*, 0.016 to 0.032 Gm. (¼ to ½ grain) by mouth or hypodermically, or *morphine sulfate*, 0.01 to 0.016 Gm. (1 6 to ¼ grain) hypodermically, necessary to relieve marked restlessness, palpitation, or precordial pain. *Reassurance* is of great importance in every case of atrial fibrillation.

In all cases of *atrial fibrillation, physical and mental overexertion, overeating, fatigue, excessive use of tobacco, alcohol, tea* and *coffee*, and *infectious diseases should be avoided.*

Severe focal infections should be *eradicated* whenever possible. Surgical operations and anesthesia should not be withheld when obviously indicated. With proper preoperative treatment, patients with advanced heart disease stand surgical procedure quite well.

When *thyrotoxicosis is present, thyroidectomy* should be considered and is usually necessary to correct the cardiac disorder. In such cases the administration of *Lugol's solution* (5 to 10 drops, three times a day) for a week before operation has a quieting effect on the heart action.

DISORDERS OF IMPULSE CONDUCTION

Heart Block: Conductivity is one of the primary physiological properties

of heart muscle. Impulses are rhythmically generated in the sinoatrial node and then spread out, more or less radially, through the atrial muscle, being propagated from muscle cell to muscle cell, at a rate of about 400 mm. per second. There are apparently no specialized pathways in the atrial muscle. Upon arrival at the A-V node, the progress of the wave of excitation (and depolarization) is slowed, the velocity of conduction through the node being very low, 200 mm. per second.

In passing through the A-V node, the impulse is delayed 0.12 second. It accelerates as it enters the large, glycogen-rich fibers of the bundle branches and their arborizations, the subendocardial Purkinje network. The rate of propagation rises to about 5000 mm. per second. Like the sinoatrial and A-V nodes, the bundle of His is supplied with ganglion cells and fibers from the vagi and sympathetics, but the branches and arborizations are apparently outside the sphere of inhibitory and accelerator nerve influence.

From the Purkinje network, the excitatory process spreads through the ventricular muscle at right angles from the endocardial to the epicardial surface, promptly giving rise to a synchronous, coordinated contraction of both the ventricles. The time required by the impulse to spread from the sinoatrial node to the ventricles is from 0.12 or 0.13 to 0.18 or 0.20 second, a period represented by the P-R interval in the electrocardiogram. The further period, *i.e.*, that elapsing between the arrival of the impulse in the ventricles and the completion of the spread of the impulse to the epicardial surfaces, is 0 06 to 0.08 second, and is indicated electrocardiographically by the QRS interval.

Interference with the spread of the excitatory process in any part of its pathway constitutes heart block. Block is only rarely demonstrable below the primary branches except for para-infarction block

Sinoatrial Heart Block: Functional or organic changes in or about the sinoatrial node may occasionally be such that the impulse originating in the node will experience increasing difficulty in its spread to the atrial muscle. In rare instances there is produced a true *sinoatrial block*. The occasional extinguishing of the impulse at its source in the sinoatrial node itself has been regarded as a vagal suppression of impulse formation. The term *sinoatrial standstill* has been suggested for this condition.

Sinoatrial block may be found in individuals who present nothing more than an excessive vagotonia, or it may follow infectious diseases such as influenza, or appear in individuals with chronic arteriosclerotic heart disease or digitalis intoxication. It may be intensified by digitalis, pilocarpine, or acetylcholine, and is usually relieved by anything that decreases the vagus tone, such as exercise, amyl nitrite, or atropine.

Atrioventricular Block: Defective atrioventricular conduction, partial and complete heart block, are the most common forms of clinically recognizable heart block. These disturbances result from an interference in the transmission of the excitatory process from the atria to the ventricles. Defective atrioventricular conduction is the term applied when each atrial contraction is followed by a ventricular beat, but the conduction time between the two is prolonged. When the conduction time is more than 0 20 second, it is abnormal. It may increase up to 0 50 second and in rare

instances up to 0.75 second, and still the regular sequence of atrial and ventricular activity may be sustained. Rarely, however, does it increase beyond 0.30 second without an occasional failure of ventricular response. The disturbance is a reliable criterion of heart disease and, even though it positively betokens pathological changes in the circumscribed tissues, it is rare that changes are confined to these structures alone.

Symptoms of this mild form of defective atrioventricular conduction are usually *nil*, but if any are present they may be considered to be due to the effect of the disease process on other parts of the heart. Complications develop slowly, but eventually these cases advance to higher grades of block.

Diagnosis. This depends upon the use of graphic methods, especially electrocardiograms, in which the increased P-R interval is easily recognized. The condition may be suspected from the presence of the presystolic gallop rhythm, the result of an abnormally wide separation of atrial and ventricular activity and sounds Normally, the sounds produced by the systoles in all four chambers, coming within 0.18 second of each other, produce sounds which blend in forming the first heart sounds. With the increase of the conduction interval between the two systoles, the sound of the atrial activity may split off and be heard as a slight presystolic element. As the interval increases, the atrial sound may be heard nearer the second sound, thus producing the protodiastolic gallop rhythm.

Prognosis. At best, the prognosis must be guarded, for in the presence of such a sign of definite heart disease, the activity of rheumatic, syphilitic, or arteriosclerotic disease in other parts of the heart may lead rather rapidly to a fatal issue. Occasionally, however, the patient may have conduction pathway damage, and relatively little other myocardial disease. In such cases, and the very rare ones that have congenital conduction defects, the outlook may be relatively good, but there is no way of foretelling this with certainty.

Partial Heart Block: The grade of heart block depends upon the degree of damage produced in the conduction tissue. The functional efficiency of damaged conduction tissue may depend, the vagus tone remaining unchanged, upon the rate at which it must conduct impulses. A slight increase of these rates, without accompanying relaxation of the vagus tone, gives rise to cumulative fatigue, which every once in a while reaches such a degree that the transmission is prevented. The impulse, if blocked, fails to reach the ventricle, and a ventricle beat is dropped. This may occur irregularly or quite regularly with or without a progressively increasing P-R interval.

The conduction to the ventricle may become so poor that only one out of three, four, five, or six atrial impulses gets through to the ventricle. Finally, a point is reached when no beats are transmitted and there is a state of complete dissociation or *complete heart block.* Under such conditions the atria continue to beat at the sinoatrial rate and the ventricles are activated by a low pacemaker at a slow, regular, independent rhythm. Idioventricular foci are of considerably slower rhythmicity and a ventricular rate of only thirty to forty beats per minute is common.

*Acute infectious diseases, especially rheumatic fever and diphtheria, are etiologic agents. Syphilis not infrequently plays a part, as does also arterio*sclerosis. Congenital defects, tumors and intracardiac disease are rare causes of block. Occasionally, slight defects may be present without much cellular infiltration and from these there is complete recovery for shorter or longer periods, *sometimes for many years, until added degenerative* changes reproduce block. This is apparently true in some cases of diphtheria. The transient nature of some of these disturbances should not lead to the error of considering them insignificant, for heart block, even though only temporarily present and reflecting a pathologic process only in a small isolated part of the heart, is always of serious moment, because changes are practically never limited to these special areas.

Complete Heart Block Pathologic Physiology: In general, it may be safely stated that only in the higher grades of heart block, such as 2:1 partial or complete heart block is there enough mechanical disturbance due to the excessive slowing of the ventricle to produce symptoms resulting *from the decreased minute volume. Some patients, with congenital, diph*theritic, or with rheumatic heart block and little other rheumatic heart disease, may continue unhampered through life Congestive failure is rare in spite of the associated myocardial conditions, probably because the *prolonged diastolic period of the slow heart permits sufficiently complete* recovery and oxygenation, and thus the extra strain that the block puts on the heart, a strain which would otherwise be a precipitating factor, is compensated unless the (idioventricular) rate drops to critically low levels *of 30 to 24.*

Weakness, fatigability, precordial pain, and abdominal pain simulating gastric ulcer are occasional complaints Giddiness, vertigo, and syncopal attacks are the common symptoms in elderly individuals, especially in those with cerebral arteriosclerosis as well as with cardiac sclerosis. The sensory symptoms of the dropped beat may frequently be simulated by sinoatrial block or standstill. Carotid sinus attacks or long postectopic pauses in some patients present similar symptoms *during and after the* postextrasystolic pause and its subsequent contraction.

Adams-Stokes Disease: The syndrome of attacks of convulsive syncope is the classical picture associated so intimately with heart block. It is a *dramatic chain of symptoms resulting from the temporary cessation of the* onward propulsion of blood due usually to a transient ventricular asystole of longer or shorter duration. This results in cerebral anemia with consequent syncope and convulsions, as a result of the prolonged suspension of ventricular action. The patient is at first markedly pallid, then flushed, and, finally, deeply cyanosed. Death may occur if ventricular contractions are not reestablished within a few minutes

The precipitating factor may frequently be primarily nervous in origin, i e., due to increased vagus tone. The disturbance is due to the fact that the ventricular pacemaker fails to initiate impulses. In rare instances of complete heart block, a short period of ventricular fibrillation may temporarily interfere with the propulsion of blood from the ventricle and produce the symptoms and signs of an Adams-Stokes attack of syncope

and convulsions. Pseudoventricular fibrillation, atrial in origin, is sometimes recorded electrocardiographically in patients with accelerated A-V conduction and pseudo bundle branch block.

Diagnosis: The diagnosis of this condition is made from observation of the total absence of the sounds of the heart beat as well as the pulse wave. Regular, muffled, soft, atrial beats may occasionally be heard during the period of asystole. The atrial phenomena or A waves are usually to be found in the congested neck veins during the period of block.

Syncopal attacks of vagus origin or vagus fainting attacks are usually of shorter duration, the pulse is greatly but gradually reduced in rate, the momentary sinoatrial standstill is rarely observed, and recognizable periods of asystole are rarely noted. The vagus attacks usually occur in young people.

The asystole, pallor, flushing, and cyanosis are not present in attacks of epilepsy.

Exercise frequently causes a disappearance of partial heart block, owing to the release of vagus tone, and with the speeding up of the heart, the block temporarily disappears.

Occasionally in complete A-V dissociation there is superimposition of atrial and ventricular systoles, causing now and then an abnormally loud heart sound Variation in intensity of heart sounds may be considered a characteristic of complete block. Another characteristic of complete heart block is the nonresponse to exertion in the majority of cases. The heart rate remains at forty or less, regardless of exercise, amyl nitrite, or atropine.

Prognosis of all types of heart block is serious. The higher the grade of block, the more serious the prognosis. Death may occur suddenly in convulsive syncope or with cardiac pain, but much more uncommonly in congestive failure with edema.

Treatment: This depends upon the symptoms, the type and extent of the heart disease, and the degree of heart block that is present. The asymptomatic type calls for the directing of therapy against the etiologic factor, whether it be local rheumatic nodules, syphilitic infiltration, or vascular changes. There is often a response to *salicylates* and *iodides.* Even *arteriosclerotic process and local circulatory disturbances are in a measure* amenable to treatment with *iodides, nitrites,* and *papaverine.*

Removal of vagal influence may be accomplished with *tincture of belladonna* in doses of 1 cc. (16 minims), *atropine sulfate* in doses of 1 to 2 mg. (1/65 to 1/30 grain), or *homatropine methylbromide (novatropine)* in doses of 0 0065 Gm. (1/10 grain) to the point of tolerance.

Digitalis, through its vagotonic effects, usually increases the degree of block, and may seriously embarrass an already impaired circulation by decreasing the number of ventricular beats per minute. The slowing may, however, afford a sufficient diastolic interval for complete cardiac oxygenation and thereby actually be beneficial. In partial heart block with frequent and disturbing episodes of complete block, it is often distinctly advantageous to digitalize the patient and put him into complete and permanent block with a regular idioventricular rhythm at the rate of forty per minute or more.

In the emergency of ventricular asystole, sharp blows to the precordium or needle pricks of the heart muscle may initiate a reflex premature contraction. *Epinephrine* or *Isuprel* 0 3 cc. of a 1:1000 solution or 3.5 mg. by intracardiac injection is justified in ventricular standstill. If available, an electronic cardiac pacer should be applied.

When Adams-Stokes attacks recur, there is necessity for medication which will stimulate or keep irritable the ventricular pacemaker. *Ephedrine hydrochloride* or *Paredrine*, each in doses of 15 mg. (¼ grain) by mouth, or *Isuprel* 10 to 15 mg. sublingually may be used hourly. In an emergency, *epinephrine hydrochloride* in a dose of 0 25 to 0.5 cc. (3 to 7½ minims) of a 1:1000 solution may be administered intramuscularly, intravenously into the jugular vein, or even into the heart muscle. The same drugs are administered every three to four hours to prevent recurrences of attacks. In complete atrioventricular heart block, quinidine and Pronestyl are dangerous. In complete dissociation cases, ventricular fibrillation has been demonstrated to develop after quinidine or after Pronestyl has been given. Bile salts may depress the idioventricular pacemaker and make more serious Adams-Stokes attacks. Ventricular fibrillation accounts for one out of ten occurrences of Adams-Stokes syndrome. Asystole must be overcome within four minutes, and the heart beat started by cardiac massage. If ventricular fibrillation is present, defibrillator shocks of 130 volts 2 amps. for 0.1 second must be applied. Repeated shocks may be necessary. Epinephrine may help by keeping the ventricular fibrillation rapid and fine, and, with massage, fibrillation may stop so that the stimulator may be applied to start the heart beat.

Bundle Branch Block: Bundle branch block is a common cardiac mechanism disturbance, the result of interference with conduction of the excitatory process below the bifurcation of the atrioventricular bundle.

The bundle branch block may be complete or incomplete, rarely partial, and may occur in either branch. There is thus a delay in the excitation of the affected ventricle until the impulse spreads to it through the muscle from the unblocked bundle branch.

Diagnosis: The diagnosis is made with certainty only by the characteristic electrocardiographic findings. There may be suggested clinically a prolonged, muffled, blurted, first heart sound Sometimes such a great separation of the sound elements occurs that the part of the first sound caused by valve closures of the promptly activated ventricle appears to come in late diastole, truly in presystole, and thus simulates the rumble of mitral stenosis. Along with the suggestive changes in the first heart sound, reduplication of the second, at the base, and a double apical thrust have been considered as almost diagnostic of the condition. Unfortunately, not more than half of the cases that are discovered by the electrocardiographic findings (the broad QRS interval of 0 12 to 0.16 second with the T waves oppositely directed to the main deflection, R and R_1 with late intrinsicoid deflection in V_1 or V_2 in RBBB and in V_5 or V_6 in LBBB) show these clinical evidences when subsequently examined.

Prognosis: In itself, bundle branch block does not produce any serious dynamic disturbance and may be well tolerated for many years; however,

the condition, especially LBBB, may be evidence of serious myocardial circulatory disturbances. Occasionally, slight provocation, such as a minor operation even under local anesthesia, may be sufficient to precipitate fatal ventricular fibrillation. On the other hand RBBB is often considered a normal variation.

Bundle branch block is occasionally temporary or transient.

Treatment: This is similar to that of other types of heart block, especially those of arteriosclerotic origin, with emphasis on the use of *iodides* and *coronary vasodilators.*

Alternation: ***Synonyms:*** Pulsus alternans; alternation of the pulse; alternation of the heart beat; alternation of the heart mechanism.

Definition: Alternation is a palpable weakness of every other regularly placed heart beat and pulse wave, resulting apparently from partial contraction of the ventricle with each alternate systole. The phenomenon is detectable not only in palpation of the pulse, but also in the taking of the blood pressure, and occasionally also in auscultation of the heart, but rarely in the electrocardiogram.

The important fact to be remembered in alternation is that the contractions of the heart are equally spaced. The right and left apical impulses occur regularly but may be visibly split as evidence of asynchronism. Alternation may be aggravated by standing the patient up and also by premature ventricular contractions.

The *pathogenesis* of the condition is quite obscure. The theory most generally accepted is that because of circulatory disturbances, the ventricular muscle recovers unduly slowly so that there is a division apparently into three unequal masses of cardiac musculature: *A*, responds during each beat; *B*, which is larger than *C*, during every other beat; and *C*, during those alternate beats when *B* fails. The beat, $A + B$, is stronger than $A + C$ because *B* is larger than *C*. The group of cells, *B*, that has just responded during one beat, having a slow recovery, is in the refractory period when the alternate impulse comes and activates the smaller muscle mass, but by the time the next impulse arrives, the larger mass is out of the refractory state and is ready to contract, while the smaller mass, *C*, that responded is refractory.

Conduction disturbances in intracardiac impulse propagation may likewise accompany these changing refractory states.

Anatomically, there is nothing that can be recognized as pathognomonic of the condition. The hearts of patients who during life exhibited this phenomenon, however, usually show extensive degenerative changes which are frequently of arteriosclerotic coronary origin, with secondary nutritional degenerative changes in the myocardium.

The patients are usually over fifty years of age, and, as a rule, present evidence of hypertensive heart disease.

Sudden strain on the heart, such as periods of rapid heart action, whether due to paroxysmal tachycardia, atrial flutter, or atrial fibrillation, may give rise to alternation. Instead of allowing time for adequate oxidation and recovery in the all too short diastolic period, the already embarrassed heart

muscle, driven at a rapid rate, recovers abnormally slowly from its fatigue and its refractory state.

Symptoms: There are no symptoms that can be referred directly to alternation. The alternation is usually associated with myocardial insufficiency, the serious symptoms of which—dyspnea, edema, congestion, and pain, as cardinal symptoms of heart failure—are present.

Diagnosis: This is usually suggested by careful palpation of the pulse; when the latter is evenly spaced, alternate weak and strong beats are detected. The condition should be looked for in all patients with chronic cardiovascular disease. It is a very simple matter to confirm a suspicion of its presence by taking the blood pressure and carefully determining the two systolic levels, one at which only half the beats come through and the other 10 or 20 mm. lower than the first level at which all the pulse waves are transmitted.

A *tracing of the pulse wave* will clearly show the alternation in amplitude. An electrocardiogram will differentiate alternation from the rare instances of bigeminy in which the premature contraction following every normal beat comes so late in diastole that the difference between the two intervals is too slight to be detected by any ordinary sense of touch or of hearing. Simultaneously taken carotid pulse tracing and electrocardiogram yield conclusive evidence.

Prognosis: The prognostic significance depends upon some of the concomitant findings. Immediately after a fatiguing episode of paroxysmal tachycardia, flutter or fibrillation, premature contractions, or sudden assumption of the upright position, alternation is not nearly so ominous as when it is found in patients at rest with a regular cardiac mechanism. In youth and early adult life the condition is probably less significant than when it appears after middle age and is *considered a reliable sign of heart disease.*

Treatment: This should be directed toward improving the general coronary circulation, and incidentally the condition of the myocardium by digitalization.

There is an intentional break in the continuity of these page numbers. This space will be utilized for further revisions of the text in this volume

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Psychosomatic Illness

Stress, conflict, frustration, and fear growing out of threatening life situations are the precipitating causes for psychosomatic disease. To be pathogenic these psychological forces must strike at a critical time when the patient's capacity for adaptation has been exhausted. The exact role which psychic trauma plays in relation to neurogenic, hormonal and somatic factors in the etiology of psychosomatic illness is still a matter involving wide differences of opinion

Most investigators now hold that psychosomatic illness is precipitated by nonspecific multiple conflicts and stress situations in the life of the patient. It is also generally accepted that for conflicts to be capable of precipitating psychosomatic illness they have to be of such a nature as to threaten the hopes and wishes of the patient or his sense of prestige and to have the capacity of setting up in his mind a sense of deep fear that his security is threatened and that he is trapped and helpless It is also held by workers in this field that for clinical illness to develop, it is necessary for conflicts or stress situations to strike at a time when the patient is vulnerable and when his adaptive capacity is inadequate to cope with additional problems.

Since it is a clinical fact that early diagnosis and treatment of psychosomatic illness favors recovery, it is essential for clinicians to be able to recognize and to appreciate when a patient's symptoms reflect conflicts and stress in his life so that emotional illness will not be overlooked. Fortunately, sufficient progress has been made in this regard that patients with functional symptoms are now seldom dismissed with the statement, "There is nothing wrong."

The physiological concepts that have been most useful in the field of psychosomatic medicine have been Cannon's[1] concept of homeostasis and his theory of flight or fight, Pavlov's[2] hypothesis of conditioned reflexes and the adaptation theory of Selye.[3] More recently experimental neurophysiology has thrown additional light on the relationship of brain structure and function and the problems of consciousness and feeling states. These relationships are discussed in the papers of Glaser,[4] Livingston,[5] MacLean,[6] Cleghorn,[7] Goldensohn,[8] Heath,[9] and Ostow[10] which were presented as a panel discussion on Recent Concepts of Central Neurophysiology.

Of particular importance to workers in the field of experimental psychophysiology has been the observation of Penfield[11] that the processes involved in memory and consciousness (awareness of environment and of

self) involved neural elements in the temporal lobes, the upper brain stem (centrencephalic system), and periaqueductal region. Two other observations in this field of interest should also be mentioned. These are Magoun's[12] findings concerning the reticular activating system in cortical activation and those of MacLean[6] in relation to the role played by the limbic lobe (the convolution surrounding the brain stem including the hypocampus) in serving as a center for emotional and visceral reactions.

The psychological and physiological effects of stress have been the subject of a number of clinical and experimental investigations during the past decade. Some of the more recent publications that deal with this subject are cited as follows: Shagass and Malmo[13] have shown that hostility is accompanied by increases in muscular tension and that high muscle tension is associated with depressed states. Streitfield[14] demonstrated in the peptic ulcer patient conflicts arising out of heavily charged but unexpressed feelings of aggressiveness. Other types of conflicts were also present as well as mixed psychological reactions of guilt, anxiety and submissiveness. It was the conclusion of this author that ulcer patients as a group tend to hold to their hostile and aggressive feelings whenever they are frustrated for fear of retaliation. Wolf[15] has published evidence to show that sudden fear results in hypofunction of the gastrointestinal tract while hyperfunction is initiated by sustained resentment. Engel[16] in his discussion of physiological responses to emotional traumata emphasized the relationship between emotional deprivation in childhood (rejection or separation from the mother) and later threats to security by some adverse life circumstance and the precipitation of a psychosomatic illness. Weisman and Cobb[17] in their studies indicated that the psychogenic factors that enter into all functional illness grow out of life's experiences and the stresses of daily living and to understand these it is necessary to become acquainted with the patient's past history, his present needs, and the frustrations in his life. These authors also point out that pathways exist within the nervous system whereby emotions can fire off somatic responses Wolff and his associates[18] contend that as long as the tension arising from emotions can be discharged over several pathways—motor, visceral, somatic, endocrine, or centrencephalic—they can be kept below the critical threshold for precipitating psychosomatic illness, but when the point is reached where the patient's adaptive mechanisms have been exhausted, then this tension results in the precipitation of the particular form of psychosomatic disease to which the patient is vulnerable.

Karush, Heatt, and Daniels[19] in their work on psychophysiological correlations in ulcerative colitis have emphasized that this condition results from hypermotility and secondary local vascular and tissue disturbances complicated by infection and triggered by emotional tension. These authors stressed that while the life histories of patients with ulcerative colitis [illegible] ade either [illegible] ict. The c [illegible] ous themes and motivations as well as conscious and unconscious fears of rejection, abandonment, and destruction. Psychologically all of these

patients were seeking, on the one hand, to find some magical resolution for their repressed aggressive feelings and, on the other hand, a cure for their somatic symptoms. These authors concluded that the character structure of this group of patients was heavily weighted with feelings of anxiety, guilt, and fears of destruction not unlike those seen in patients with paranoid schizophrenia.

White, Grant, and Chambers[20] have made a study of twenty patients with classical angina pectoris and compared them with twenty patients who suffered from angina innocens. This study showed that the clinical symptomatology in both groups of patients was precipitated by prolonged chronic emotional tension associated with insecurity growing out of threatening or deteriorating life situations. Patients with angina pectoris were given to denying the importance of their symptoms while patients with angina innocens reacted with labile emotions and showed persistent anxiety and deep foreboding over their condition Pain was more diffuse in the angina innocens group; depressive features were commoner in the angina pectoris group Patients with angina innocens suffered the type of anxiety that drove them from doctor to doctor seeking relief. The incidence of familial coronary artery disease was highest in the angina pectoris group. Seventy-five per cent of the patients with angina innocens improved with supportive psychotherapy while only thirty per cent of the patients with angina pectoris were benefited.

In a study of a series of twenty-five patients suffering from thyrotoxicosis Mandelbrote and Wittkower[21] have found that their group of patients tended to have psychological reactions marked by anxiety coupled with subnormal assertiveness and a tendency to depression. The conflict picture involved inordinate need for affection, disturbed mother-child relations, and feelings of rejection There was also evidence of poor and ineffective emotional and psychosexual adaptations throughout the lives of these patients. It was the conclusion of these authors that Graves' disease has a complex etiology involving both psychological factors of maladaption, tissue and genetic factors

Alexander and Visotsky[22] in a report on asthma in a seventy-two year old patient have presented a study of the sequence of emotional events leading up to the attack. These consisted of the impending fears of having to leave the home in which the patient had lived for forty years with the background experience of never having had to face the psychological experience of separation and loneliness in her previous seventy-two years of life Concurrently with the development of the threat of separation, the patient reacted to it with asthma. These authors concluded that in asthma the central emotional factor consists of fear growing out of the threat of separation from a mother or a mother substitute. These authors also conceded that for the emotional trauma to precipitate asthma there must also exist an underlying predisposing tissue factor.

Leigh[23] has proposed that an excessive vagal discharge over a period of hours is the primary cause of death from asthma in those patients who do not expire primarily as the result of infection or cardiac failure. In the case of a patient age forty, whose death was studied by Leigh, there was

excessive secretion of mucus resulting in mucous plugs from both excessive bronchosecretion and bronchoconstriction. Leigh interpreted these findings as resulting from abnormal parasympathetic stimulation following the excessive release of emotional tension. Leigh has proposed as the result of his findings that patients with severe asthma should be atropinized prior to any psychotherapeutic interviews that might be capable of touching off or releasing heavily charged, repressed emotions in patients with status asthmaticus.

It is entirely due to the clinical psychiatric investigation of the emotional reactions seen in patients that we owe the present understanding of the role played in psychosomatic illness by repressed hostility or by fears of rejection or separation from a key supportive figure in the life of the patient or by feelings of insecurity as the result of a threatening life experience. Most schools of psychiatric thought today agree that there is no specific relation between the type of psychosomatic illness and the type of conflict a patient experiences. Instead present research thinking emphasizes the total conflict picture and the exhaustion of the adaptive mechanisms of the patient. There is, however, great interest in the timing and intensity of the conflict situation and there is full recognition of the fact that the more intense the subjective and symbolic meaning of conflicts to the patient the greater their capacity to bring about exhaustion of the adaptive mechanisms of the personality.

In regard to personality types there seems to be a lowered threshold for psychosomatic illness among those individuals whose character structure has become rigid and stereotyped as compared to those whose character structure reflects more flexibility and adaptability. Other character traits associated with increased vulnerability to psychosomatic illness are emotional immaturity, abnormal dependency, passive submissiveness, avoidance of responsibility, avoidance of competition, and the denial of the need for affection.

The psychopathology seen most frequently in psychosomatic illness revolves around a constellation of conflicts and frustrations arising out of the following: Repression of hostility because of fear of retaliation; ambivalent attitudes (love and hate) towards a key supportive figure in the life of the patient associated with feelings of guilt, rejection, inferiority, or insecurity; projection of hostility because of unacceptable instinctual drives; emotional isolation associated with the denial of the need for affection.

The social pathology most frequently seen in the lives of psychosomatic patients centers around disorganization in family structure, broken homes, divorce, and desertion, discordant family relations; noncohesive family ties, resulting in the failure to instill children with family ideals or to teach them rules for living; nonaffectionate parents who fail to make their children feel wanted or loved; socioeconomic distress with the attendant stress of poverty.

In addition to emotions there are also operating as etiological forces in psychosomatic illness neurogenic, chemical, and somatic forces. From the standpoint of treatment, at our present level of knowledge, nothing, however, can have greater meaning to the clinician than to have skills and

ability to gain psychological insight into the conscious and unconscious conflicts and frustrations of his patients. The following analysis of conflictual situations in the lives of patients common to psychosomatic illness is necessarily incomplete but it may serve as a guide or as an aid for a better understanding and better acceptance of the patient and his illness on the part of his physician.

The three commonest fears that are seen in psychosomatic illness are: (a) The fear of being rejected or abandoned for the expression of any aggressive or hostile feelings; (b) the fear of being separated from the key supportive figure in the life of the patient, *i. e.*, the mother, the wife or husband, etc.; (c) the fear of being punished because of unacceptable instinctual drives.

The conflict situations seen most frequently in the various psychosomatic syndromes, as reported in the literature, are listed as follows

Peptic Ulcer: Conflicts arising out of submissive, passive and dependent wishes associated with feelings of repressed hostility and ambivalence (love and hate) toward some key protective figure in the life of the patient. Conflicts arising out of wishes for self sufficiency and independence associated with feelings of doubt, insecurity, and inferiority.

Ulcerative Colitis: Conflicts arising from fears of being separated from or rejected by the supporting figure in the life of the patient (parent, beloved person, boss, or superior); conflicts arising from fear of social punishment (rejection by the group) because of unacceptable drives or wishes; conflicts arising from fear of failure.

Hypertension: Conflicts arising out of unacceptable aggressive wishes associated with the feeling that these must be repressed by intellectual self control.

Palpitation and Extra Systoles: Conflicts arising out of guilt over competitiveness and feelings of unconscious hostility over identification with one parent and ambivalent attitudes toward the other parent.

Rheumatoid Arthritis: Conflicts arising out of overly aggressive and passive submissive personality components associated with excessive self-control of emotions and latent feelings of guilt, anger, and rebelliousness.

Bronchial Asthma: Conflicts arising out of being separated from the mother or mother figure associated with latent guilt and fears of punishment because of socially forbidden instinctive drives (anger, aggressiveness, sex).

Thyrotoxicosis: Conflicts arising out of fear of the loss of affection; conflicts arising out of fear from a sudden increase in responsibility; conflicts arising out of fear of the loss of prestige

Neurodermatitis: Conflicts arising from opposing emotional drives; conflicts between dependency and self sufficiency, passivity and aggressiveness, acceptance and rejection associated with feelings of insecurity.

Tics: Conflicts arising out of fears of bodily injury usually associated with *striving for competitive goals beyond the capacity of the personality.*

Migraine: Conflicts arising out of aggressive feelings toward a prestige or beloved person that must be repressed for fear of retaliation, associated with a high degree of intellectual control over emotions, coupled with strong ambitions and perfectionistic drives and fear of failure.

Persistent functional symptoms accompanied by fatigue, irritability, emotional lability, and difficulties in personal relations are seen in varying intensity in all psychosomatic illnesses. To estimate the significance of these findings in regard to the prognosis for recovery is one of the challenges facing clinicians dealing with these conditions. The prognosis in any case of psychosomatic illness is a judgment weighted by many considerations involving the patient's personality and the nature and intensity of his conflicts, the circumstances of his life situation and the reversibility or irreversibility of the somatic pathology. If the patient's emotional difficulties arise out of conflicts in personal relations or from the failure to gain a life goal or from an unchangeable life situation the prognosis for recovery is unfavorable unless the patient can learn, with the help of psychotherapy, to accept or to adjust to his problem or unless his problem disappears because of some favorable change in his life circumstance. All patients instinctively hope that they will not have to change and tend to *cling magically to the hope that their life circumstance will change in their* favor. The physician's skill in dealing with these unrealistic magical hopes is a determining factor in whether the patient recovers or stays ill. It is essential that such unrealistic ideas be replaced by more realistic and positive thinking on the part of the patient.

Patients whose symptoms reflect a transient conflictual situation retain their potential for spontaneous recovery; patients faced with prolonged conflictual situations lose their capacity for spontaneous recovery and need help and direction if they are to have their best chance for recovery. It must be recognized that at our present level of knowledge, treatment in the form of psychotherapy is not always effective and the best efforts at therapy often fail either to cure or to bring about an amelioration of symptoms. This is particularly true of those patients who have been repeatedly crushed by life's experiences to the point where they consciously and unconsciously expect only failure, or in those patients whose life and family relations are hopelessly tangled in conflict, or in those patients whose personality structures reflect only disturbed, nonaffectionate human relationships.

The problem of treatment in psychosomatic illnesses is further complicated by the prejudices and unrealistic or nihilistic therapeutic attitudes of physicians in regards the role played by psychotherapy in functional illnesses. If this problem is viewed realistically it must be admitted that on the one hand there are no curative drugs, and on the other that psychotherapy is not always effective in resolving the conflicts, frustrations, and disappointments that lie deeply rooted in the mind of the patient or which exist because of the stresses of life.

The first point for the physician to bear in mind is that patients are

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unable to meet the demands that life makes upon them. A second point is that functional somatic symptoms are one of the body's ways of signaling the existence of intolerable frustration. It is as though the body, under these circumstances, served as a psychological indicator that the mind is trou-

bled and disturbed. A third point that is most helpful in setting up a favorable therapeutic climate in which the psychosomatic patient may live, is for the physician to move immediately and positively to meet the patient's "Wish To Be Helped."

The move toward helping a patient to define and understand his problem in all its meanings and dimensions is psychotherapy The goal of psychotherapy, on the one hand, is to give the patient sufficient insight to see his problem as it really is (destruction of unrealistic or magical thinking), and, on the other hand, to establish a close, supportive, emotional relationship of healthy dependency on the physician so that the patient can take some positive action to solve his problem.

The emotional attitude of the physician toward the patient and his problem sets the stage for all the interactions designed to help the patient. The physician's role is to become closely identified with and understanding of the patient and to convey, by his own attitude of tolerant understanding, a realistic sympathy and a positive, warm desire to help. Angry, authoritative, defensive, or insecure attitudes on the part of the physician are harmful and hurtful in that they reinforce the patient's unconscious fears and fix his symptoms. Common sense judgments and values must prevail at all times. Questioning of the patient should be kindly and indirect. Interrogation must be avoided, instead the patient should be interviewed and led to discuss his problems. The following type questions are useful to ask patients·

What do you feel is important in your illness?
What else comes to mind about the way you feel?
Is there anything in addition you would like to speak about?
Do you feel comfortable when you are alone? When you are with others?
What is it that you believe upsets you?

A willingness to listen is the best way to lead the patient to discuss spontaneously his conflict problems. Then with skills born of permissiveness and friendliness the physician can lead the patient into a discussion of his close personal relations involving either parents, siblings, the beloved and supportive figure in his life, or his bosses or superiors.

For a disturbance in personal relations to play a critical role in psychosomatic illness it has to be capable of threatening the emotional or personal security of the patient (as the patient sees it). For children these conflicts revolve around their positive and negative feelings directed at the parents or at their siblings that are compounded of hostility, jealousy, and rejection within the family setting. For adults these conflicts revolve around the love relationships in their lives or from their conflicts with their peers and equals.

There are three emotional stereotypes seen in psychosomatic patients. The first is the aggressive, self sufficient patient who projects his anger on the physician. If he is to be helped, it must be through the understanding that his anger, under such circumstance, is an example of the reaction formation and displacement and is not true personal hostility. The second emotional stereotype is the anxious, fear-ridden patient who runs away from his problem If he is to be helped, his fears have to be understood

and allayed and he has to be given positive emotional support and be helped over his problems as they arise. The third emotional stereotype is the passive submissive, dependent patient who takes refuge in his illness and denies his own capacity. This group of patients are frequently so crushed by emotional trauma throughout their lives or have learned from earliest childhood to depend on others to solve their problems that they are looking for the physician to take full responsibility for their care and to arrange for some magical solution to their problem. This group of patients is very difficult to help because of the nature of their conflicts and their own character makeup. No matter what the nature of a patient's problem or his life's experience or character structure, the positive wish and willingness to help, on the part of the physician, is the first step on the path to recovery. It is always essential as part of the effort to bring help to the patient not to fail to set up a daily schedule for healthy activity and to provide for periods of work, rest, recreation, and play. Once these steps have been taken, the patient is receiving the best help and is being provided with the best care within the limitations of our present knowledge

REFERENCES

1 Cannon, W B The Wisdom of the Body, Norton, New York, 1932
2 Pavlov, I P Conditioned Reflexes, Oxford, London, 1927.
3 Selye, H Stress, Acta Inc Canadian, 1950
4 Glaser, G H Recent Concepts of Central Neurophysiology, Psychosom Med 17·5, 337, 1955
5 Livingston, R B Some Brain Stem Mechanisms Relating to Psychosomatic Functions, Psychosom Med 17·5, 347, 1955
6 MacLean, P D The Limbic System (Visceral Brain) in Relation to Central Gray and Reticulum of the Brain Stem, Psychosom Med 17 5, 355, 1955
7 Cleghorn, R A The Hypothalmic Endocrine System, Psychosom Med 17.5, 367, 1955
8 Goldensohn, E S Role of the Respiratory Mechanism, Psychosom Med 17.5, 377, 1955
9 Heath, R G · Correlations Between Levels of Psychological Awareness and Physiological Activity in the Central Nervous System, Psychosom Med 17.5, 383, 1955
10 Ostow, M · Psychic Contents and Processes of the Brain, Psychosom Med 17·5, 396, 1955
11. Penfield, W · Memory Mechanisms, Arch Neurol and Psychiat. 67.178, 1952
12. Magoun, H W An Ascending Reticular Activating System in the Brain Stem, Arch Neurol, and Psychiat 67 145, 1952
13. Shagass, C, and Malmo, R B Psychodynamic Themes and Localized Muscular Tension During Psychotherapy, Psychosom Med. 16:4, 295, 1954.
14 Streitfield, H S · Specificity of Peptic Ulcer to Intense Oral Conflicts, Psychosom Med, 16 4, 315, 1954
15 Wolf, Stewart Physiology of Mucous Membranes, Diseases of the Digestive System, ed 3, Portis, S A, Lea and Febiger, Philadelphia, 1953
16. Engel, George· Selection of Clinical Material, Psychosom Med 16 5, 368, 1954
17. Weisman, A, and Cobb, S Neurology, Diseases of the Digestive System, ed 3, Portis, S A, Lea and Febiger, Philadelphia, 1953
18 Wolff, H G : Stress and Disease, Thomas, Springfield, 1953
19. Karush, A, Heatt, R B, and Daniels, G E Psychophysiological Relations in Ulcerative Colitis, Psychosom Med 17 1, 36, 1955

20 White, K. L., Grant, J L., and Chambers, W. N: Angina Pectoris and Angina Innocens: Diagnosis and Management of Chest Pain, Psychosom Med 17:128, 1955

21 Mandelbrote, B M, and Wittkower, E D · Emotional Factors in Graves Disease, Psychosom Med 17.105, 1955

22 Alexander, Franz, and Visotsky, Harold Asthma, Psychosom Med, 17 470, 1955.

23 Leigh, Denis. Sudden Deaths from Asthma, Psychosom Med. 17 232, 1955

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Psychosomatic Aspects of Cardiovascular Disease

"Psychosomatic" is a new term, but it describes an approach to medicine as old as the art of healing itself. It is not a new specialty but rather a point of view which applies to all aspects of medicine and surgery. It does not mean to study the soma less; it only means to study the psyche more Its subject matter is founded on the important advances in physical medicine as well as on the biologically oriented psychology of Freud, without whose epochal discoveries no work on psychosomatic medicine could be attempted. It is not a new discovery, but rather a reaffirmation of the ancient principle that the mind and the body are interactive and interdependent, a principle that has always guided the intelligent general practitioner. Indeed the traditional old family doctor very often was an excellent psychosomatic physician, although he never thought of himself as such. His patients usually were intimate friends, and he was as familiar with their emotional life as with their physical peculiarities. He was well aware that the two frequently were closely related As a science, psychosomatics aims at discovering the precise nature of this relationship

Largely due to the impetus given to this approach by World War II, we are beginning to understand that emotional factors are important in illness and that they can be studied in the same way that tissues can be studied; in other words, that there is a psychopathology just as there is a tissue pathology, and that the only way to stand on safe ground is to study both the somatic reaction and psychic reaction at the same time. Let us study cardiovascular disease from this standpoint.

ANXIETY AND THE HEART

In spite of the enormous incidence of cardiovascular disease, the majority of patients who have symptoms referred to the heart region do not have evidence of organic heart disease. The reason is not hard to find From time immemorial, the heart has been the traditional seat of the emotions, and hence acts as a focal point for anxiety. No other body organ is used so frequently in a symbolic way to refer to love and hate, which, as W. C. Menninger[15] pointed out, should lead us to think of the emotional significance of disturbances involving the heart. As a symbol of love we are familiar with the use of the expression "warmhearted," "loving with all my heart," "heartfelt." We speak of being "lighthearted," and of the heart

"bounding with joy." But we also speak of being "heavyhearted," and of "the heart growing weary." Then, too, we refer to the "fainthearted," and the "chickenhearted"; or think of the heart "racing with fear," of "fluttering or trembling." Hate and hostility are expressed in such terms as "hardhearted," "heartless," and "coldblooded." An unhappy person is spoken of as suffering from "heartache," or of being "heartsick."

Do these expressions, however, have any real meaning from the standpoint of psychopathology? Is there any actual relation of anxiety and the anxiety attack to disorders of the heart and the cardiovascular system? The answer is obviously "yes." Anxiety neurosis stands in close relation to physiologic changes and is therefore of utmost significance to all branches of medicine. This relation to physiologic changes is especially close in the cardiovascular system Moreover, anxiety neurosis, in its varying degrees, is probably the most frequent disorder of civilized life. The various forms of the anxiety attack were described by Freud[7] more than a half century ago. Not only did he call attention to disturbances of cardiac function such as palpitation, arrhythmia, tachycardia, but he also spoke of the disturbances of respiration and a host of physiologic changes that are so often, today, regarded as evidences of vasomotor instability or autonomic imbalance. Furthermore, Freud emphasized the fact that these attacks are not always accompanied by recognizable anxiety This, of course, is one special reason why they are so often regarded as indications of physical disease. For almost fifty years clinical medicine has taken practically no cognizance of anxiety neurosis, except, perhaps, by adopting the term, devoid of its meaning, for all possible states of fear and anxiety.

"FUNCTIONAL" HEART DISEASE

Cardiac neurosis* arises in predisposed persons who have been subjected to a precipitating factor. Such persons carry an unusual amount of anxiety in their makeup. Then under special circumstances that anxiety is attached to the heart largely because the heart is regarded as the all important bodily organ and is associated with the idea of sudden death.

This anxiety, or even the personality predisposition, may be anything but obvious, and yet in reviewing the histories of patients with cardiac neurosis, it is interesting to note how frequently one obtains the story of some "nervous breakdown," either during the period of school life or in the course of some later period of stress. In an excellent paper on this subject, Conner[1] called attention to the following four groups of causes which may act as the precipitating events:

1. *The statement of some physician or life insurance examiner* that the heart shows some abnormality such as a murmur or irregularity of rhythm; or the rejection of the applicant for life insurance on the score of some heart disturbance or of "high blood pressure." Sometimes it is the mere assumption on the part of the applicant himself that the heart must be diseased because two or three examiners were called in to listen to it. In

* It is hardly necessary to say that the designation "neurosis with cardiac manifestations" is much more satisfactory but, because of tradition, the term "cardiac neurosis" will probably continue to be used

a person predisposed, the slightest suggestion that the heart is not right may be enough to start the whole train of reactions that lead up to the development of cardiac neurosis. In regard to so-called neurocirculatory asthenia this problem is of the greatest importance in the examination of young men for army service. Unusual attention to the cardiac examination or some casual remark may be the starting point for later disability.

2. *The occurrence of some dramatic case* of heart disease perhaps with sudden death among relatives or friends of the patient. This is a frequent precipitating factor for cardiac neurosis particularly if the patient has been in close contact with the relative or friend or has actually nursed such a person. The continual emotional stress plus hard work and often lack of sleep prepare the way for the development of the first heart symptoms.

3. *The appearance of some symptom* which calls the attention of the patient to his heart and leads to doubt as to its integrity. This may be a sudden skip, a flutter, or a twinge of pain, or it may be merely undue palpitation or dyspnea after convalescence from some illness, such as an attack of grippe. It is possible for such symptoms to appear as a result of the excessive use of tobacco or coffee.

4. *Some profound and protracted emotional disturbance*, such as deep grief or prolonged anxiety, in which, however, there is at first no element of doubt concerning the state of the heart. This was strikingly illustrated by the innumerable instances of the condition known as irritable heart of soldiers, effort syndrome, or neurocirculatory asthenia which developed in World War I. As a result of the profound and long-continued emotional disturbance incident to the process of volunteering or being drafted into the army, such cases were encountered by the thousands and far outnumbered all the cases of organic heart disease found by the examining boards.

To these four groups we may add a fifth—*the occurrence of an anxiety attack* which causes palpitation and frequently leads the physician to incriminate the heart. More will be said on this point later.

In connection with this discussion a thoughtful paper by Hart[10] emphasizes that more attention must be paid to the underlying neurosis and less to the so-called iatrogenic factor. Hart correctly states that it is difficult to disturb a stable person by raising the suspicion of heart disease whereas it may be impossible not to disturb the unstable person. It is the unstable person, already suffering from chronic anxiety neurosis, who "puts words in the doctor's mouth" regarding the presence of heart disease. Thus, even if the physician is most cautious the patient who is looking for heart disease may find indications of it in the doctor's words or manner. We have difficulty protecting ourselves against this and again Hart correctly points out that the real iatrogenic factor in cardiac neurosis is not so much an error of commission as of omission, that is, in neglecting the overall medical needs of the patient The physician who contents himself with the effort to exclude organic heart disease, thus hoping to reassure the patient, and fails to investigate the underlying neurotic problem, is the real offender.

SYMPTOMS

Under circumstances such as those that have just been discussed, pain in the heart region, fatigue, sighing respirations, insomnia, ringing or pound-

ing in the ears, and faintness, dizziness, nervousness, irritability, and flushes are apt to make their appearance. At first, there may be only discomfort in the heart region with the later development of other symptoms, particularly fatigue, which may be overwhelming and lead to complete invalidism.

The chief symptoms group themselves under the headings:

1. Pain and distress in the heart region.
2. Dyspnea and fatigue.
3. Palpitation or heart consciousness.
4. Tachycardia and other disturbances of rhythm.
5. A group of symptoms which include all of the above in addition to evidences of vasomotor instability. This is often looked upon as a special form of cardiac neurosis, occurring especially in military life, and referred to as effort syndrome, neurocirculatory asthenia (N.C.A.), or disordered action of the heart (D.A.H.).

Pain: Bishop[1] estimated that twenty-five per cent of all patients visiting the office of a cardiologist have cardiac pain as a primary complaint, and Harrison,[9] in a valuable study, to which further reference will be made, estimates that pain in the chest is present in from fifteen to twenty-five per cent of all adult patients who need hospital care. It need hardly be said that all pain in the cardiac region does not originate in the heart.

Angina Pectoris: When characteristic effort pain with its peculiar distribution occurs in a hypertensive arteriosclerotic individual, there is no problem of diagnosis—angina pectoris is present regardless of other findings. Unfortunately, however, the diagnosis of the anginal syndrome not infrequently must rest solely on subjective phenomena. Abnormal physical signs, x-ray, and electrocardiographic evidence may be absent. It is important to recognize that the discomfort of the anginal syndrome appears with few exceptions when additional work is imposed on the heart. The abnormal sensation is usually of relatively short duration; it rarely lasts for more than a few minutes. It frequently disappears promptly when the patient rests, and in the majority of instances after the administration of nitrites. The discomfort is described usually as being beneath the sternum. The distribution of the pain is variable; it may appear in the left arm; sometimes the pain extends into the abdomen; at times, but less commonly, into the back and occasionally into the jaws and the face. As we shall see the pain of cardiac neurosis usually has different characteristics.

Harrison regards the most important features in the diagnosis of angina pectoris as (1) the history of relationship to effort, (2) the short duration of pain, and (3) the demonstration that the amount of muscular effort required to induce the pain is increased by glyceryl trinitrate. A very important aspect of the subject is that a large percentage of patients with angina pectoris also suffer from chest pain due to other disorders and these disorders may either be related to the angina pectoris (as in the case of myocardial infarction and reflex disturbances of the skeletal system) or unrelated to it (as in the case of gallbladder disease, hiatal hernia, esophageal spasm, and the like). Because of the frequent coexistence of two causes of chest pain, one of them may be overlooked unless unusual care is employed in obtaining the history, which Harrison finds is the single most

important method of examination, and in many patients is more important than all other procedures combined.

Harrison finds that when electrocardiograms are taken following muscular effort, changes of the S-T segments and of the T waves of such a nature as to be specifically suggestive of the presence of angina pectoris may be encountered in fifty to sixty per cent of patients. This was true not only of his study but from other studies that have been reported.

A word should be added regarding the relation of emotional factors to electrocardiographic changes. Wendkos[22] has shown alterations in the T wave in the precordial lead in patients with neurocirculatory asthenia indistinguishable from those associated with structural heart disease. Mainzer and Krause,[13] in a study on the effects of fear on the electrocardiogram showed that on the operating table immediately before induction of general anesthesia, an abnormal electrocardiographic record, in comparison with the tracing of the previous day, was found to develop in roughly two-fifths of fifty-three cases. These alterations were observed in persons with cardiac disorders, where they merely accentuated the pathological character of the cardiogram already existing, and also occurred frequently in patients with normal cardiograms. While in a number of patients the changes disappeared under the anesthetic, or at least by the next day, in some cases they were still encountered twenty-four hours after operation.

In pseudo-angina careful analysis will usually show evident differences from true anginal pain. Rarely is the pain referred directly to the retrosternal region. Usually it is located in the apical region or over the left half of the precordium. Usually, too, it is made up of twinges of darting pain, and the steady, boring, constricting character of anginal pain is lacking. There is seldom any close relationship between the pain and physical effort. Indeed, the pain is much more apt to be felt when the patient is sitting quietly or is in bed than when walking But it may have the characteristic features of true anginal pain and occasionally the recognition of its real nature must rest on the other factors present. For example, let me refer to the frequent problem of the obese woman of menopausal age with a labile blood pressure who complains of severe lancinating pain in the precordial region, breathlessness, and fatigue Has she or has she not angina pectoris? If we remember that the pain of cardiac neurosis bears no definite relationship to effort, is frequently described as sticking, needle-like, or soreness, that it is often associated with inframammary tenderness and hyperalgesia, so that the pressure of the stethoscope sometimes elicits it, and that it may be accompanied by a sense of choking as well as sighing respirations, we will have no difficulty in the differential diagnosis, particularly when we associate these symptoms with the whole picture and life situation of the individual with cardiac neurosis.

The differential diagnosis of pain in the chest may be a most difficult problem and is never to be regarded lightly. In any patient with pain in the chest, no matter how closely it may seem to the related to emotional factors, very careful physical studies must be made. In closing this discussion of cardiac pain I cannot emphasize this point too strongly.

Dyspnea: Shortness of breath is the most common symptom of heart disease, but it also occurs for a variety of other reasons; for example, in lung diseases such as emphysema and bronchial asthma, in anemia and obesity, and in the air-hunger of acidosis. But the dyspnea of actual heart disease occurs either directly as the result of exertion or in attacks of cardiac asthma The dyspnea is determined by the vital capacity, which is reduced in patients with cardiac disease as a result of pulmonary congestion

For our purpose we may conclude that cardiac dyspnea is in the main a reflex rather than a chemical disturbance and that its most important cause is congestion of the lungs. Therefore, it seems strange that dyspnea of functional origin, which has nothing to do with congestion of the lungs, should be so frequently mistaken for the shortness of breath of organic heart disease. Here the dyspnea is due to anxiety, although the anxiety may not be recognized. Indeed, the shortness of breath often has a symbolic meaning. Although the patient describes "shortness of breath," careful questioning often will reveal that what he really has is a sensation of a weight on the chest—"a load on the chest"—which he can get rid of by talking about his problems. It is an inability to obtain a deep breath, together with a sensation that the air taken into the lungs is insufficient and that it does not enter deeply into the lungs. When an effort is made to overcome this sensation, it leads to periodic sighing or "sighing respirations," and frequently the patient will demonstrate this in the course of an examination. For example, if he is asked to show what he means by shortness of breath, he will place the hand on the lower sternum or epigastrium, take a deep sighing respiration and then often describe the feeling that the lungs seem insufficiently filled with air. Occasionally it is true that if the patients are suffering from severe emotional strain or anxiety, hyperpnea develops to the extent that hyperventilation tetany or syncope may result. Indeed, the test of hyperventilation in such subjects will frequently bring about evidences of tetany such as a positive Chvostek sign. It is of great importance to differentiate this sighing respiration from dyspnea of cardiac origin.

Palpitation: Heart consciousness, arising either from tachycardia or arrhythmia or both, is a very frequent symptom in the cardiac neuroses and often leads to a mistaken diagnosis of organic heart disease. But it is also true that just as the heart may be speeded up by emotion, so may it be slowed, and occasionally during anxiety attacks, especially in nightmares, great slowing of the heart, apparently from vagal stimulation, occurs. More frequently, however, the heart is speeded up in its action, and this, together with premature contractions, may lead to heart consciousness. Sometimes this is only apparent when the patient is lying on his left side or in certain periods, but occasionally the patient is aware of the heart all of the time When organic disease of the heart has been eliminated and when significant arrhythmias have not been demonstrated one can feel quite certain that the awareness of the heart action is to be explained psychologically. Instances of actual auricular fibrillation occurring during periods of emotional stress, which did not seem to have an

organic basis, have been encountered. Palpitation is sometimes the very first symptom of a cardiac neurosis. In the patient who has been prepared from the standpoint of his psychological makeup, certain life situations, such as prolonged emotional stress, plus such other factors as overindulgence in coffee and tobacco, will make a slight twinge or a skipped beat a sufficient stimulus to call attention to the heart, and from that point on he may suffer from palpitation. Then, as Oille[17] pointed out, if the physician gives medicine "to help prevent the irregularity" or makes the statement "the missed beats are not important if they don't get any worse," a cardiac neurosis has been established.

Murmur: Probably no single objective finding leads to more false diagnoses of cardiac disease than a murmur. A systolic murmur can be found in a large number of healthy young adults if they are examined in various postures, in different phases of respiration, before and after exercise. These functional murmurs are also much more common during fevers. They are rather faint, but sometimes moderately loud, and are heard in the apical or pulmonic areas. Kilgore[12] feels that if not very loud, if not high pitched, if markedly changed by respiration and posture, and if not accompanied by other signs of heart disease (especially enlargement of the heart), by deficient heart function, or by a history of rheumatism or chorea, these systolic murmurs should not be regarded as pathologic. And in the case of borderline systolic murmur—some of the louder ones, less clearly dependent on posture or respiration—the diagnosis of valvular disease, if suspected but not confirmed by other physical signs, should, in general, be held in abeyance until radiographic and electrocardiographic studies have been made.

The first point in the prophylaxis of cardiac nuerosis enters in regard to this problem. If there is any question regarding the significance of the murmur the patient had better not be apprised of the fact or even made suspicious of heart disease until one can marshal his evidence in order completely to exonerate the heart. This is of special significance in regard to recruiting of young men for military service. The beginning of a cardiac neurosis can often be traced to the indiscreet remark of an examining physician who detects for the first time a systolic murmur at the apex of the heart unaccompanied by other evidence of organic disease.

TREATMENT

Prophylaxis is the first thing to consider. This means that in people predisposed because of their neurotic personality structure or chronic anxiety neurosis the physician must be careful not to focus attention upon the heart in the course of a general physical examination, such as for insurance purposes, military reasons, during recovery from infectious disease, or, more important still, during an anxiety attack. In the last instance, especially, our behavior must match our words and when we tell such a patient that he does not have evidence of organic heart disease we must not say hesitatingly, "I do not think you have heart disease." On the contrary, we must say very definitely, "you do not have heart disease," and then instead of cautioning rest or giving "heart" medicine, which of

course increases the patient's suspicion that we are not telling the truth or that we don't know, we must make the recommendation "to carry on in spite of symptoms" and be prepared to deal with the underlying neurosis.

Once cardiac neurosis has developed the problem of eradicating the idea of heart disease from the patient's mind and re-establishing health becomes more difficult. In some instances it is relatively simple and a tactful explanation of the situation and reassurance may be all that is needed. But depending upon the severity of the underlying neurosis and the length of time that the cardiac symptoms have persisted, the problem may be very difficult. Under such circumstances the services of a trained psychiatrist may be necessary, but generally it is the attending physician who must assume the responsibility and care of such patients. This question will be discussed later.

History and Physical Examination: It goes without saying that the first *thing is a careful history and physical examination. Often it* is wise to carry out additional studies because a casual announcement after a hasty and superficial examination that "there is nothing the matter with the heart" will almost certainly fail to carry conviction. But there must be a point at which examinations stop and at that point one must say with certainty, "there is nothing the matter with your heart." Then if the patient can be persuaded to accept without resentment the idea that his symptoms are of emotional origin, the battle is half won. From that point on, the liberal application of reassurance and encouragement plus an effort to understand the underlying neurosis will often accomplish a great deal. But the reassurance must not be simply that of the spoken word; the patient must be shown how to reassure himself by a demonstration that his symptoms can be made better rather than worse by the exercise and effort which he has been afraid to take.

Therefore we plan a program for the patient, using common sense of course in what we ask him to do. We do not ask a patient who has been incapacitated for months to go out and do a full day's work. On the contrary, we set an easy task at first But we do say, "this much we know you can do and you must do it regardless of how you feel." That means that if you ask the patient to walk a block he must do so regardless of whether he feels faint or whether he feels that he will die before he gets back. It is a kind of specious reasoning but I often say, "I will accept the responsibility for anything that happens to you" and this seems to be very persuasive to this type of patient.

Kilgore,[12] in an excellent paper on the subject, emphasized the fact that once we have eliminated the idea of organic heart disease we must then tell the patient that his slogan must be "carry on in spite of symptoms." This is a very successful way of handling such patients, and of course their confidence mounts in proportion to the degree of accomplishment.

Drugs: If medicines are used the patient must have a definite understanding that they are palliative rather than curative and that they have nothing to do with the heart itself. For example, if small doses of sedatives are used, it is wise to explain to the patient, "that they take the edge off his nervousness." The use of digitalis is, of course, a blunder. No intelli-

gent patient could possibly be persuaded that his heart is sound if at the same time he is asked to take digitalis. If any rest in bed is to be recommended, and sometimes the patient will have to resort to some rest in the beginning, he must understand that this has nothing to do with his heart; that it is simply a question of his having used up energy and that "his storage battery needs recharging." But for him to believe that the cultivation of a horizontal philosophy of life is going to cure him is erroneous because too much rest simply plays into the unconscious tendency to remain sick. In the final analysis, it is the cultivation of an erect philosophy of life that is going to accomplish cure. The use of massage, hydrotherapy, and gymnastic work must be looked upon not only from the standpoint of possible beneficial results but the unhealthy suggestions that can come from such sources must be considered Again and again it has been my experience that people who do not work directly with physicians, but rather in institutions that are developed solely from a commercial standpoint, are very prone to give the patient suggestions that are bad for him, not necessarily deliberately, but by taking the pulse and commenting about it, taking the blood pressure and telling the blood pressure figures, referring to the muscle tone as bad or the circulation as poor, etc., they work harm rather than good. Subjects who develop cardiac neurosis usually do not tolerate coffee or tobacco well and I have found it useful to limit coffee and stop tobacco. This need not be an undeviating rule because some patients can tolerate both, but the point is that many tense people find momentary relaxation from the nervous cigarette habit but the end result is a bad one and the only way they can stop is to quit rather than to cut down.

Psychotherapy: All of this, however, only leads to a consideration of psychotherapy which is the fundamental method of treating the cardiac neuroses. Such management is very often rewarded by results that are just as satisfying as any in the field of internal medicine. I said before that this is usually a problem for the general physician. Certainly we cannot send all such patients to psychiatrists; these problems are so numerous that general physicians must learn to deal with them Just as there is a minor and major surgery so there exists a minor and major psychotherapy. However, if a major disorder exists we must be able to recognize it and send such patients to psychiatrists. Furthermore, we must do our best to educate our patients and medical profession to look upon psychic ailments in exactly the same way that they look upon organic ailments, that is, that there is no stigma to be attached to an illness simply because it is of emotional origin and hence there is no disgrace and certainly nothing to be ashamed of in consulting a psychiatrist.

Explaining the Illness to the Patient: Having determined then that we are dealing with cardiac neurosis (anxiety neurosis with cardiac manifestations) we first of all examine our patient as carefully as we can in order to rule out an organic disease but also, as mentioned in the beginning of the discussion, for the purpose of establishing a basis for psychotherapy, because there is nothing so valuable as a thorough history and a complete physical examination in establishing a good relationship with the patient. It is then that you can say to the patient and the statement carries con-

viction, "You do not have organic disease; this illness is of emotional origin." I use the latter term, emotional origin, advisedly because I find that it is the best way to explain to an intelligent patient that the illness is psychogenic. Patients often resent the term "just nerves" or the impression that they sometimes gain from an unsympathetic physician that they are malingering. To say that the illness is functional does not offer sufficient explanation and patients frequently do not understand. To apply to the illness a term such as neurocirculatory asthenia, effort syndrome, or hyperthyroidism is simply to delude yourself or to delude the patient. And yet this is frequently done just because the physician feels that he must give the illness a name and because he does not know how to approach the patient from an emotional standpoint. Hence the illness gets the name of a physical disease and often the unfortunate kind of treatment that goes along with it.

The problem is not an easy one because the patient is apt to insist, "but there must be something the matter"—he cannot understand that so much distress can occur unless some vital organ is seriously affected. Moreover, if you do succeed in reassuring him for the time being, he may continue to hold the reservation, "but if this sort of thing continues surely something will happen," in other words, "how long can my heart stand this?" Telling the patient to control himself is like trying to hold back steam under pressure; if it doesn't come out the spout it tries to blow the lid off the tea kettle. As long as the discussion is kept on the level of trying to persuade him that he does not have physical disease one gets no place because you cannot argue with an obsession. One must get at the mixed feelings, the conflict, that underlies the anxiety and this can only be done by encouraging the patient to talk about his personal problems. This discussion will usually have to do with the family group. For example, in a patient whom I saw recently—a young married woman caring for a sick mother—the feelings of respect and devotion opposed to the inner resentment at the effort and cost and disruption of her own family life, led to anxiety which could not be dealt with as long as the approach was on the level of reassurance regarding the absence of organic disease, telling the patient that she must control herself, and giving phenobarbital.

It is an unfortunate circumstance, as far as scientific psychologic medicine is concerned, that no matter what you call the illness, if the patient has sufficient confidence in the physician, any kind of treatment may cause an alleviation of symptoms and many doctors build up great reputations without really understanding the nature of such illnesses. What I am suggesting is that we call a spade a spade but attempt to do it in a way that the patient will understand. This, of course, is taking a chance with certain patients because, do what you will, they may resent the inference that the illness is emotional, largely due to the belief—because we have will power and because we have intelligence—we ought to be able to handle "our nerves." But, of course, it is true that without help and without enlightenment a patient cannot handle anxiety of unconscious origin any more than he himself can handle an acutely inflamed appendix.

Organ Language: To go on with this method of handling such patients, once we have told them that the illness is emotional we may use illustrations

of how the emotions influence the functions of our body in order to show them that their emotions may be responsible for symptoms. Such examples as blushing, gooseflesh, vomiting, and diarrhea, as well as pallor, racing pulse, and palpitation, occurring for various emotional reasons, are usually convincing. I say to them that if they have an emotional problem which they cannot express by word or deed, the tension arising from that emotional situation must express itself somehow and the organs of the body may take over the function of expression by a language of their own—"every psychic tendency seeks adequate bodily expression." Hence if an individual finds it difficult to swallow, instead of an obstruction in the gullet, it may be some situation in the environment that the individual "cannot swallow." If the person "cannot tolerate something on his stomach" it may be something in his life situation that he cannot tolerate and the stomach is simply expressing it because he, for some reason, cannot. If he has "a load on his chest" that is represented by sighing respiration, or a "weight *on the heart" that produces discomfort, the relation to his* own illness is brought even nearer. This kind of an illustration will often permit a patient to talk freely about some problem that has been disturbing him perhaps more than he knew. Indeed, it is the very fact that such things are unconscious that makes it necessary for the body to express the emotions in such a primitive fashion as "organ language." Therefore, we must strive to make the matter conscious, and if we succeed, it is likely that the particular symptoms will disappear. In other words, we must encourage our patients to talk about their "other troubles" in order to find out about the present trouble To put it another way, the more we can persuade our patients to talk about themselves as human beings rather than as medical cases the sooner we will come to understand their symptoms of emotional origin. This is usually best done by skillfully and tactfully directing the conversation rather than by asking direct questions. These matters are discussed in some detail elsewhere[21] so that I can only add a word of caution here. It is often better to allow the patients to discuss matters of an intimate nature, such as sexual problems, without asking direct questions concerning these matters. If the patient has confidence in his physician he will frequently introduce these matters of his own accord, but if it is necessary to ask questions it must be done in a way to indicate that such matters are perfectly natural, like any other natural function of the body, and that you are not asking as a matter of morbid curiosity. In other words, you are scientifically and not morally interested.

Another point that may now be stated is that it is much better to listen than to talk. In other words, to give advice about important personal matters such, for example, as marriage and divorce is a distinctly dangerous matter for the physician to atttempt. It is much better for him to listen, and to allow the patient to see his problems, perhaps in a slightly different way, and then to come to his own conclusions about highly charged emotional matters.

NEUROCIRCULATORY ASTHENIA

In spite of the many studies and great amount of attention that has been given to the subject of neurocirculatory asthenia, there is still much

uncertainty regarding this disorder. This uncertainty is chiefly over the question of its relationship to the nervous system; in other words, what part emotional factors play in the development of the disorder.

Designated by DaCosta[5] as "irritable heart," in his description of this cardiac dysfunction noted in soldiers of the American Civil War, it became known in World War I as "neurocirculatory asthenia." The latter name was suggested by a team of medical reserve officers[18] of the American Army sent to England to study the condition with Sir Thomas Lewis, whose term "effort syndrome" is the British equivalent.

From the very first description by DaCosta it has been recognized that emotional factors enter into the problem of neurocirculatory asthenia. However, the relative importance of the role played by the emotions has been the source of much dispute.

Cohen and his associates have been studying this disorder for several years, and their many contributions are widely accepted as authoritative.[3] Their studies are largely concerned with physiologic measurements and long-term observations of the course of the disorder. Their experimental observations, which bear on the nature and severity of the symptoms and disability, demonstrate that abnormalities which are slight or absent at rest become pronounced with stress. Cohen's description of the disorder is the clinical picture of psychoneurosis, and since he holds the term "neurocirculatory asthenia" to be synonymous with "anxiety neurosis" and "neurasthenia," one would expect to find some consideration of psychodynamics and psychotherapy in his work. But this does not prove to be the case. A psychodynamic approach is excluded as unscientific, and simple reassurance with passage of time is held to be as effective as prolonged psychotherapy, psychoanalysis and other forms of treatment. Wheeler and his co-workers[23] state that they are "unable to distinguish between patients with neurocirculatory asthenia as diagnosed by cardiologists and anxiety neurosis and neurasthenia as diagnosed by psychiatrists." Most observers would agree with this statement.

Margolin's remarks[14] are to the point. "The syndrome which in 1917 was named neurocirculatory asthenia was originally observed in military combat situations. Anxiety neurosis, on the other hand, is a syndrome that was defined in a civilian environment. With the establishment of these two terms to cover a relatively unclassified group of somatic and psychic symptoms, anxiety neurosis and neurocirculatory asthenia began to appear as diagnoses in both civilian and military settings. It is important to realize that neurocirculatory asthenia as a term stresses the pathophysiological manifestations, whereas anxiety neurosis calls attention to the psychopathological phenomena. The significance of this distinction becomes apparent when the psychiatrist diagnoses anxiety neurosis in a patient who, according to the internist, exhibits neurocirculatory asthenia. In addition, this difference may be expressed by the patient's choice of his presenting symptom which may be psychological or physical. In fact, this unconscious selection may determine whether the patient will be referred to the psychiatrist or to the internist."

Cohen[2] states that "cardiac neurosis is not a disease or diagnostic entity; most patients thus labeled probably have neurocirculatory asthenia." Most observers would turn this sentence around.

Miles and Cobb[16] disagree with the disregard of the importance of psychogenic factors and look upon "neurocirculatory asthenia" and "anxiety neurosis" as opposite ends of a continuum, with the former diagnosis reserved for those patients who have evidence of a constitutional physiologic deficit. They think of the differentiation in terms of a frequency distribution curve with a few relatively straight "somatic" cases at one end and a number of clearly "neurotic" cases at the other. The majority of cases they would regard as mixtures that fall somewhere in between, according to the proportions of the factors involved. They believe that this sort of division, rather than a clear-cut dichotomy, is of fundamental importance and still not sufficiently appreciated in medical thinking and teaching. They feel that the vagueness of the term "neurocirculatory asthenia," when defined merely by a list of symptoms, results in confusion and increases the difficulty of interpreting research data. It is not the label to which they object, but rather the concept of the disease that is implicit in a truly descriptive diagnosis.

Wittkower and his associates,[24] in a study of fifty unselected soldiers with "effort syndrome," delineated five personality types among them, and none was found to be emotionally well adjusted The majority conformed to the obsessional type, but in an everyday view of their personalities important emotional problems might easily be overlooked.

Wheeler and his associates[23] attempt to evaluate therapy by comparing a group of their patients with so-called neurocirculatory asthenia who were largely untreated, except by reassurance and the passage of time, with a heterogeneous group of subjects having psychologic disorders treated in other clinics by various medical and psychotherapeutic procedures, and conclude that their patients did just as well as the treated group. To make this type of comparison hardly seems adequate, and Walker[20] feels that the deduction is supported by figures that could be used equally well to draw an opposite conclusion.

One would have no quarrel with a physiologic study of neurocirculatory asthenia or any other condition so long as the author did not draw psychologic conclusions from a nonpsychologic study.

Cohen objects to the "anecdotal method" in the study of neurocirculatory asthenia, but it all depends on who is listening to the anecdote. It is like interpretation of the microscopic image, which depends upon who is looking through the eyepiece. A person trained in psychodynamics listening to the story of a patient with neurocirculatory asthenia discovers (1) that the symptoms are those of psychoneurosis, (2) that the family history shows a high incidence of psychopathology, (3) that a long-term study of the life history indicates neurotic personality structure, (4) that a cross-sectional study of the life history at the time of onset of symptoms shows emotionally disturbing events that are specific for that particular personality, (5) that discussing this material brings out meaningful behavior on the part of the patient, and (6) that dealing with this material has psycho-

therapeutic value.[21] Therefore, to neglect psychodynamic factors in patients with neurocirculatory asthenia means that one excludes from the field of observation the most important part of the clinical picture. This aspect is implicit in Cohen's treatment of the subject—from his use of the terms "anxiety neurosis" and "neurasthenia" as synonyms for neurocirculatory asthenia (even though he separates the terms from their psychologic meaning); in his description of the disorder, which is identical with psychoneurosis; in his attempt to evaluate treatment by comparing the disorder with a heterogeneous group of psychologic disorders treated in other clinics; and even in his own treatment, which is largely concerned with reassurance and a study of "social" factors I agree with Miles and Cobb[16] that "unless one makes some attempt not only to measure the constitutional or physiologic factors but also to understand the psychodynamics of the illness and of the therapeutic processes as well, it seems unlikely that even the most objective and scientific investigations can prove fruitful" While we cannot measure human behavior with the same precision with which we measure the physiologic disturbances which reflect that behavior, it is nevertheless true that neurosis has its own distinctive features to be discovered by personality study and that only in this way can diagnosis be correctly made and proper treatment instituted.

From the standpoint of the practical management of these disorders I think that the use of the term "neurocirculatory asthenia" does more harm than good It calls attention to a part when the disorder is one of the whole. It implies that the circulation is somehow at fault. My feeling is that medicine would be better off without the term "neurocirculatory asthenia," which only confuses the patient and often leads the physician to feel that he understands the disorder because he has given it an imposing name. There is less objection to the term "effort syndrome" (which leaves the way open for further investigation rather than closes the subject with a pretentious name), though the symptoms are not confined to exertion.

The term "neurocirculatory asthenia" has come to carry the connotation of constitutional inadequancy, which is so easy to incriminate, while the emotions are so difficult to study. But, as Walker[20] states, the physician who believes that the patient has symptoms because he is made of "second-rate stuff" cannot hide this attitude from the patient. He also feels that it is more rational to focus attention on factors which can be modified rather than on those that only Providence can alter.

The designation "neurocirculatory asthenia" appeared on the horizon about the time when "shell-shock" was at the height of its popularity. The former seems to me just as bad a name as the latter because it is based on a misconception and perpetuates invalidism. If one refers to an illness of emotional origin in terms of organic disease, one fosters neuroticism. If it is called a disorder and explained in terms of behavior, the patient is immeasurably better off. To use an analogy pertaining to another part of the body: we have seen the rise and fall of the term "colitis" and the evil effects of giving this name to a neurotic patient with an "irritable bowel" syndrome. Neurocirculatory asthenia is just as bad a name as "colitis," and "irritable heart" is worse than "irritable colon," because

people are more concerned about the heart than the colon. It is the person that is at fault and not the colon, and the same is true in regard to the cardiovascular system in the patient with neurocirculatory asthenia.

Since neurocirculatory asthenia does not exist without neurosis or character disturbance, I suggest that the condition be called neurosis, using the proper psychiatric designation, and adding qualifying terms if necessary.

HYPERTENSION AND ANXIETY

Pain in the precordium, palpitation, dyspnea and fatigue are symptoms frequently associated with the cardiac neurosis that occurs in patients with hypertension. When these symptoms are present in a patient with a normal cardiovascular system, and the general medical examination reveals no other abnormality, it is not as a rule difficult to assign them to their proper sphere—the emotions. When hypertension is present, however, it is almost invariably held to be the responsible factor. Under such circumstances psychosomatic study will frequently reveal that the symptoms are out of proportion to the disease and that there is much conflict in the personality makeup. The high blood pressure frequently makes its appearance in a setting of emotional stress in which there is a specific relationship between the emotionally disturbing event and the personality conflict, or, at least, symptoms appear which are attributed to the hypertension. Whether or not the hypertension is an evidence of the personality decompensation is difficult to say, although infrequently the hypertension does seem to be brought about by the personality factor. In other words, often it is impossible to tell whether the high blood pressure did or did not precede the symptoms which led to its discovery and whether or not the symptoms can be attributed to it. Nevertheless, as soon as the blood pressure elevation is discovered and the patient informed, the "blood pressure phobia" appears.

It is easy for a physician to slap a blood pressure cuff on the arm of a patient and say, "It's your blood pressure"; it is difficult to spend time with a patient trying to find out something about the emotional life. Once the diagnosis of "high blood pressure" has been established, attention is concentrated on the effort to "bring the blood pressure down" The patient demands to know the blood pressure figures; on each visit to the physician he waits with anxious concern to hear the latest reading, and frequently he has ideas of "stroke," "heart failure" or "Bright's disease" in the back of his mind.

The phobia becomes the predominant part of the clinical picture, and the symptoms are only an exaggeration of the premorbid personality trends. In benign hypertension often the best treatment is simply an effort to deal with this "blood pressure phobia" by reassurance, minimal preoccupation with blood pressure figures and weird diets, the advice to "carry on in spite of symptoms," and the attempt to understand the patient as a person. Of course, other medical problems must not be neglected.

Thus, in regard to symptoms in association with hypertension, one must always question the relation of the symptoms to the high blood pressure itself and make an effort to understand them from the viewpoint of behavior.

When pain in the chest is associated with hypertension in a middle-aged person, and especially in the presence of physical evidence of cardiovascular disease, the problem becomes a difficult one from the standpoint of management. It is all very well to advise a young person invalided by cardiac neurosis who has only moderate elevation of blood pressure and no evidence of cardiovascular disease "to carry on in spite of symptoms," and to encourage him to do the things that other people do. But in the presence of electrocardiographic evidence or other indications of coronary disease, one assumes a heavy responsibility in encouraging such patients to carry on; yet to caution rest on the one hand and try to give reassurance on the other is often worse than useless. To the young physician treating such a patient, and to psychiatrists as well, it poses a difficult problem; the sudden death that may occur in patients who have been encouraged to carry on, or who are undergoing psychotherapy, may bring the criticism of the community down upon the head of the unfortunate practitioner. And yet to play into the patient's unconscious fears by cautioning rest and more rest leads to greater and greater degrees of invalidism. Moreover, as the patient waits for his arteries to harden, the questionable benefit of the physical rest is more than offset by the physiologic burden provoked by psychic stress. The only advice that I can offer in this regard is that the patient must be evaluated as carefully as possible, both physically and psychologically, and then an effort made to advise him correctly about his activities. Tension of emotional origin is just as burdensome to the cardiovascular system as effort of physical origin.

ANXIETY AND ORGANIC HEART DISEASE

There has long been discussion as to whether emotional factors cause or even influence "organic" disease. This is especially the case in regard to cardiovascular disease. Many physicians take it for granted, for example, that a psychic event may precipitate coronary occlusion. The proof that is advanced is usually only on the basis of a time relationship, that is, it is pointed out that just before the occlusion occurred something of an emotional nature happened. Opponents point out that everybody is subject to emotional stress; they insist on the greater importance of the physical changes and minimize emotional circumstances as purely coincidental or at most as having slight influence.

The debate if stated in these terms can never be settled, because it overlooks the structure of the personality and the reaction of the whole organism, which is at the same time both physical and mental. A person with physical disease, though its apparent "cause" may be an external agency of some kind, is likely to be affected emotionally as well. Emotional crises may have an influence on the progress of the illness, and psychiatric intervention may hasten convalescence or retard degenerative processes. On the other hand, a burden of repressed anxiety, resulting in prolonged muscle tension or other bodily changes, may place too heavy a strain on some organ or organs, which in time develops a disorder that is diagnosed as functional. Such a case, if taken in time, may be rendered symptom-free by adequate psychiatric treatment. Whether the activating agent be physical or mental, the disease process itself has both aspects. The mere

discovery of unpleasant circumstances in the life situation of an individual is no indication of emotional complications and still less of psychogenesis of the difficulty. As Dunbar[6] has stated, the significant questions concern the patient's ability to adjust to such situations, his pattern of reacting to them, the degree of anxiety in his makeup, the nature and seriousness of his conflicts, and his physical defects and patterns of physical behavior.

In an important study of symptoms referable to the cardiovascular and respiratory system[25] occurring in patients with and without structural disease of the heart, a detailed, day-to-day physiological and psychological investigation was made of the way individuals respond to a standard exercise test as determined by certain cardiovascular and respiratory measurements.

Emphasis was placed upon the reactions to persistent low-grade stresses and strains which are a part of "everyday" living and which constitute the core of the bedside problem rather than upon the well-known responses to major crises.

Their results indicate that, in a setting of adverse life circumstances and associated emotional reactions, performance in terms of respiration and work of the heart is costly. This high cost may manifest itself in cardiovascular symptoms which are not dependent alone upon gross structural heart disorder. This uneconomical performance may also manifest itself in impaired total efficiency of the individual.

Attention was called to the fact that "heart pain in the presence of anatomical narrowing of the coronary arteries may result from increased work of the heart attendant upon prolonged elevation of the blood pressure and cardiac output in association with rage, resentment, anxiety, fear, and tension." But they also note that "heart pain in the presence of anatomical narrowing of the arteries may result from a fall in the cardiac output and coronary blood flow in association with desperation and defeat." The latter they refer to as the hypodynamic response. Even though coronary thrombosis occurs frequently in persons with hypertension, this does not minimize the possible importance of the hypodynamic reaction in coronary thrombosis. "Although it is generally accepted that a rise in cardiac output and subsequent increase in the work of the heart are more effective in producing myocardial ischemia and pain, a fall in minute volume would also decrease the coronary blood flow and, in addition, given a pre-existing occlusive disease of the coronary arteries, could present an optimal state for the development of myocardial infarction Such a set of circumstances would explain some instances of anginal or coronary thrombosis occurring in individuals during inactivity or immobilization in bed and accompanying surgical shock."

The observations of Hickam and associates[11] do not support the concept of relation between type of emotion and circulatory change, although their work, as well as that of Grollman[8] and Stead[19] and co-workers show that emotion may increase cardiac output by two-thirds, and occasionally more.

As indicated in the previous discussion, many contributions have been made to the subject of the cardiac neuroses, and it is quite generally appreciated that such disorders are psychogenic in origin and that psychotherapy is essential in treatment. But it has not been recognized that

psychologic factors are even more important in organic cardiovascular disease. While a neurotic with a normal heart may suffer a great deal subjectively, and may even have a disturbance of cardiac function marked by various forms of arrhythmia, the heart, certainly in the majority of such patients, remains structurally healthy. I am not referring to the involved psychosomatic problem of whether long-continued emotional stress can produce structural changes in the cardiovascular system. This is a problem for the future. I am referring only to what are generally acknowledged to be unequivocal psychosomatic relationships.

The neurotic patient who has organic heart disease may add a real burden to the work of the heart, either through constant tension of psychic origin or, more especially, by means of acute episodes of emotional origin. Thus, a cardiac breakdown may be hastened which might be indefinitely postponed if there were no psychic stress. Therefore, psychic factors may be even more important than physical factors in producing incapacity. In the latter type of case, by working with and through the emotional life of the patient, disabilities which would otherwise progress may be stopped and often a great deal of improvement can be brought about.

EMOTIONAL PROBLEMS OF MYOCARDIAL INFARCTION

Any pain from nose to navel must be taken seriously and the various physical studies that are necessary must be done. Then, if one can safely exclude physical disease, the question of reassurance arises. Reassurance alone may need constant repetition, so that one must do more than that—he must try to understand the background of the anxiety so that symptom formation may not be inevitable.

When one deals with anxious people with diseased hearts, the question often arises whether the general physician, psychiatrist or both should be responsible for the patient. There is always the question whether the general physician ought to ask his colleague in psychiatry to assume responsibility for such patients, and yet often the psychiatric problems are beyond the capacity of the average physician or cardiologist. Certainly under such circumstances the cooperation that is necessary requires that each have considerable understanding of the other's discipline.

Often after myocardial infarction the heart heals, but the patient remains an invalid for anxiety reasons. Here personality study will permit the physician to judge whether the patient is one who accepts dependency, thinks in terms of retirement, and becomes an invalid (perhaps subsisting on insurance benefits) or will fight against dependency, perhaps erring in the other direction by refusing suggestions and indulging in rash behavior. One may have to deal with guilt and hostile feelings; nor should it be forgotten that the coronary age is also the period of diminishing potency and many sexual problems arise that are capable of causing great tension which also have to be considered in relation to the coronary circulation. Finally, depression is often masked by heart symptoms; it must be recognized and appropriately dealt with.

PSYCHOSIS IN CARDIAC DISEASE

In order to complete this consideration of anxiety and the heart, the frank psychoses, of exhaustive or toxic nature, which occasionally compli-

cate advanced heart disease ought to be mentioned. This phase of the subject, however, is well treated in many textbooks of medicine and cardiology. Other than to say that the psychosis sometimes occurs very insidiously and that the form which it assumes depends upon the underlying personality of the individual, the subject will not be dealt with further. One must be aware of the fact, however, that just as the emotions may influence the working of the heart so may advanced disease of the heart aggravate or precipitate emotional disorders.

REFERENCES

1. Bishop, L F., and Bishop, L F, Jr Am J Sc 182·19, 1951
2 Cohen, M E: Proceedings, First National Conference on Cardiovascular Disease New York, American Heart Association, 1950
3 Cohen, M E, and White, P D Psychosom Med 8 335, 1951.
4 Conner, M A J.A M A 94 447, 1930
5 DaCosta, J. M: Am J M. Sc 61 17, 1871.
6 Dunbar, F.· Psychiatry 2·167, 1939
7. Freud, Sigmund Collected Papers Vol 1, p 76, Internat Psa Press, New York, 1924
8 Grollman, A: Am J. Phys. 89 366, 1929
9 Harrison, T R Am J M Sc 207 561, 1944
10 Hart, A D: J A M A. 156 1133, (Nov 20) 1954
11. Hickam, J. B, Cargill, W H, and Golden, A J Clin Invest 27 290, 1948.
12 Kilgore, E S J A M A 117 258, 1941
13 Mainzer, F., and Krause, M British Heart J 2 221, 1940
14 Margolin, S: Presented before the Psychosomatic Forum, New York City, 1950
15. Menninger, W C: Southwest J Med 21·281 and 324, 1937.
16. Miles, H H W, and Cobb, S New England J Med 245·711, 1951
17. Oille, J A. Canad M A. J 45 1, 1941
18. Oppenheimer, B S, and others Mil Surgeon 42·409, 1918
19 Stead, E. A, Jr., Warren, J V, Merrill, A J, and Brannon, E S: J Clin. Invest 24·326, 1945.
20. Walker, W J Am Heart J 42 97, 1951
21 Weiss, E, and English, O S Psychosomatic Med., 2nd ed, p 59, W B Saunders Co, 1949, Philadelphia
22. Wendkos, M H: Am Heart J 28 549, 1944
23 Wheeler, E. O, White, P D, Reed, Eleanor W, and Cohen, M. D J A M A 142 878, (March 25) 1950
24 Wittkower, E, Rodger, T F, and Wilson, A T M Lancet 1 531, 1951.
25. Wolf, G A, Jr, and Wolff, N G Psychosom Med 8 293, 1946

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Trauma of the Heart

Introduction: Trauma of the heart may arise as the result of wounds and direct violence and also from strain of effort. From one or other of these causes varied lesions may develop, but the cases are exceptional; it is difficult both to collect the evidence and to assess it judiciously. There are two chief problems. On the one hand when a definite heart lesion is manifest after violence or strain, we must rely chiefly on the medical history in making a decision as to whether the condition is the result of trauma or is due to natural causes; and if due to trauma as to whether the heart was already diseased before the event in question. On the other hand, following injury or alleged strain we meet with apparent disease of the heart, as for example a possible contusion of the myocardium or a case suggesting cardiac overstrain, when it may be difficult to decide as to whether the heart itself has been injured at all

Experimental work with regard to direct violence has indicated the possibility of numerous lesions occurring as the result of this form of trauma; but most experiments relating to strain or overstress of the heart have proved that all parts of the healthy heart are capable of withstanding considerable strains.

The function of the heart as judged by exercise tolerance tests is hard to assess. White in 1937 drew attention to the fact that neurocirculatory asthenia and, "muscular flabbiness," are more easily exposed by exercise tolerance tests than is true heart disease. We are compelled to place considerable reliance on the patient's own statements, when they are consistent. Modern methods of investigation have helped sometimes with regard to the condition of the heart muscle in cases of trauma, but only if the opportunity for examination is taken early, and probably in many cases of myocardial injury the findings would be negative.

Perhaps the extended use of instruments of precision has tended to lessen our interest in case histories. All forms of trauma are becoming increasingly bound up with litigation, which militates against an open mind. Trauma of the heart is essentially a study of case histories, using the word history in the widest sense of that term.

The subject may be divided under the following headings: (1) Disorders of rhythm; (2) valvular disease; (3) contusion of the heart; (4) wounds of the heart, and (5) primary cardiac overstrain. In some cases of contusion of the heart, a disordered rhythm or a valvular lesion may be coexistent. It is easy usually, but not possible always, to distinguish between direct violence and internal stress.

DISORDERS OF RHYTHM

Auricular Fibrillation

When this condition develops in the course of the natural history of a diseased heart, it is possibly the result of the many small strains which daily life entails. It may arrive, however, as a sudden event, as the result of overstrain or direct violence to the chest wall. In some cases mental excitement may be an added factor. The recorded examples usually have been middle-aged or elderly men, but some of them would appear to have had a heart perfectly normal before the trauma. Hay and Jones[26] recorded five cases of auricular fibrillation, of which four were due to sudden physical exertion, and one to electric shock They state that four of the patients were apparently well before the exciting cause or accident. Two of them were under forty years of age.

Two cases, the result of overstrain, have come under my own observation. One was a man known to have mitral stenosis, but leading an active life until a sudden unexpected lifting effort caused distress with fibrillation supervening. The other example is as follows:

A workman in good health, aged fifty-five years, undertook some heavy lifting work to which he was not accustomed Sudden pain developed across the chest and he felt weak and dizzy He was short of breath going home and this symptom increased He rested at home for a fortnight and his doctor noted an irregular heart This was confirmed as auricular fibrillation by electrocardiogram. There were no other abnormalities Five weeks after the strain normal rhythm was restored by quinidine.

Kahn and Kahn[43] recorded cases of auricular fibrillation following direct trauma of the chest wall. It is the predominant feature in two cases recorded by Kissane in 1927 as contusion of the heart. Several examples of this event described by Warburg[71] and one by O'Farrell[56] ended fatally. The prognosis is less favorable than when it results from strain, because there is risk that there may be structural damage of the heart. I have met with it on two occasions after a man has been knocked down by a motor car. There was no evident bruise on the chest wall or actual history of blow over the heart, so that direct trauma, sudden strain and excitement may have acted together. Both were elderly and possibly liable to the disability, but in good health for their years. To take one example already recorded:[6]

A man, aged sixty-one years, acting as a night watchman, was knocked down by a motor car on January 21, 1932. He was taken to the casualty department at the Derbyshire Royal Infirmary; about this he remembers little. After being detained for a few hours, he was sent home by car to rest in bed. He noticed that he was short of breath and his doctor recognized an irregular pulse. The shortness of breath persisted, and although his external injuries were trivial, it was obvious that his capacity for exertion was entirely changed. Seen by myself in December, 1932, auricular fibrillation was recognized by electrocardiogram. There were no other abnormalities. There was no congestive failure. Five years later his condition was unchanged

My other patient had a scalp wound which is of interest because Bramwell[19] has recorded the case of a coal miner, aged thirty-five years, in whom

auricular fibrillation was present after a blow on the head. A few quite exceptional precipitating causes have been recorded; for example, the shock of a severe scald, inhalation of poisonous fumes, and the writer has met with the condition following a heat stroke in a workman. Normal rhythm was restored by quinidine a few weeks later. Enig and Rud[78] noted this form of arrhythmia on several occasions in men who had been buried by a fall of sand.

We may conclude that auricular fibrillation is a definite disability which may result from trauma either in the form of direct violence or more commonly from overexertion. When the disability is the result of overstrain there is distress at the time with dyspnea on slight exertion. In those cases due to direct violence the cardiac symptoms may be masked by the shock of the trauma and there may be delay before the fibrillation is recognized. In hearts already diseased the life history is changed. The event may take place when the heart previously was efficient and apparently normal. In a number of cases quinidine has restored normal rhythm, but relapse may occur.

Auricular Flutter

The disposing causes of this condition are similar to those which produce fibrillation. Kahn[42] noted this disorder following a blow over the chest. Congestive failure developed with fatal termination four months after the injury. There was no autopsy. Walker[70] admitted this event and White in 1937 stated that flutter is commonly precipitated by sudden effort, excitement, trauma or surgical operation.

One case of auricular flutter came under my own observation in 1935 after a fracture-dislocation of the cervical vertebrae. From the hospital records it would appear that flutter developed several days after the accident while in bed. It is difficult to find a reasonable explanation, but the fact remains that when the man recovered from his surgical injuries he was incapacitated by reason of the heart condition There was evidence of a hypertensive heart, but one cannot entirely ignore the injury as a possible exciting cause of the flutter

Extrasystolic Arrhythmia

This irregularity is not a definite entity and is no disability in itself. We may only conclude that there is an irritable focus in the heart muscle. It is present sometimes after overstrain, real or alleged, and is perhaps due to a neurosis in some of these cases. It has been met with after a blow over the precordium, in which case there may have been some injury to the pericardium or heart muscle. Judicious treatment should minimize the significance of any symptoms which may result from this arrhythmia. Tobacco or other disposing causes must be considered. But although extrasystoles in themselves have little influence on the heart capacity, they are rarely met with in hearts that are perfectly normal, and they have some significance after trauma. Kissane[46] produced ventricular extrasystoles experimentally in dogs after a blow over the chest.

Heart Block

Heart block with fatal termination has been noted in some seriously damaged hearts. There is, however, a number of records of heart block as the only obvious disability following injury. Kissane[46] produced this condition experimentally in dogs The most convincing clinical records are those in which the condition is temporary, which is in about one-third of the recorded cases; but there are well authenticated examples of the disability persisting Warburg[72] cited ten examples from medical literature and White and Glendy[75] two others. Traumatic heart block is recorded by Arenberg,[5] Coffen,[24] Tuohy and Boman,[68] and Campbell.[23] The writer[9] obtained a tracing of complete heart block about one hour after a young man had been crushed against a wall by the radiator of a motor lorry. Radiology revealed a slight degree of edema of the lungs. There was, however, little distress; but the abnormal rhythm persisted. The functional capacity of the heart, as noted by Goldman[34] in a case of heart block following a bullet wound, is good compared with that of heart block from natural causes.

With a slow pulse following injury it is important to obtain a tracing without delay to distinguish between injury of the conducting bundle and simple sinus bradycardia, which is also a sequel of direct violence to the thorax.

Tuohy and Boman[68] recorded temporary partial heart block after the strain of a heavy lifting effort. The patient recovered in a month. I have seen no similar record and the incident is not readily explainable.

Ventricular Fibrillation

With the animals already connected with the electrocardiograph, Bright and Beck[20] recorded death from this disorder following a blow in two dogs, and Kissane, Fidler, and Koons[48] note one such event in their experiments. If immediate death results from a direct blow over the heart, and there is no evidence postmortem to account for the fatality, ventricular fibrillation is a reasonable explanation. Jokl[41] cited a boxing fatality in which this event seemed probable.

Disorders of the Heart Rate

Auricular paroxysmal tachycardia may be precipitated by trauma as noted by White and Glendy[75] and Barber.[9] The writer has also observed a case of nodal tachycardia lasting sixteen days following the fracture of several ribs.[9] Kissane[46] cites an example from a similar injury and in both cases the nodal tachycardia came on a few days after the accident. Schlomka[65] when inducing trauma in animals occasionally set up *ventricular tachycardia*, but there are no similar clinical records.

Sinus bradycardia has been reported in animal experiments. Of four examples in my own clinical experience three were free from symptoms but one[8] felt faint about an hour after a "steering-wheel" accident. He recovered soon after when he came to hospital with a pulse rate of thirty-six. The electrocardiogram showed no other abnormality. The bradycardia persisted for two days, while under observation in hospital, but being symptom-free he was allowed to go home. When he reported on the

seventh day the rate was seventy-two. Kissane[16] recognized a case and Jokl[41] quotes an example after a blow when boxing.

In reference to these disorders of heart rate, and perhaps some of the arrhythmias, it is of interest that Osborn,[58] in a large series of accident autopsies, found bruising of the posterior aspect of the right auricle in a number of cases, in which death had resulted from injuries unrelated to the heart.

VALVULAR DISEASE

From Strain: Rupture of a valve from strain or overexertion is a lesion well known which has been recognized for more than 100 years Peacock[59] discussed the problem in his Croonian Lectures. There is immediate and urgent distress with precordial pain. There will follow varying degrees of heart failure. The physical signs of a traumatic valvular lesion are similar to those of valvular disease due to natural causes. The diagnosis of trauma is based on an accurate history, and if possible evidence with regard to the heart condition previously. Sometimes there is a bruit of unusual type or intensity, and in one of my own records the patient himself could hear the unusual noise, which developed after a lifting effort.

The aortic valves are those most liable to this form of injury. There is evidence that the valves were already diseased before the accident in the majority of cases, but there are some records[39,40] in which it would appear that the valves were not affected with rheumatic, syphilitic or other chronic disease; although of course there may have been some slight defect of structure. There is no doubt that many of the patients have had no consciousness of disease before the event.

Rupture of a mitral valve from strain is rare, although it has been recorded by Allbutt[2,3] and by several other observers. A more probable accident in this region is rupture of one of the chordae tendinae, which gives rise to similar signs and symptoms. Peacock[59] recorded the event after severe vomiting in a child with well compensated mitral stenosis; and Horton-Smith[38] described rupture of chordae tendinae in a workman aged thirty-three years due to strain. There was immediate pain with dyspnea, followed by passive congestion He died in three months. At autopsy the valves showed no evidence of previous disease.

Allbutt[3] in mentioning certain cases in which a sudden strain appears to have caused structural damage, suggests these may be extreme instances of an agency always at work, in some degree, in those who do heavy manual work. This is an interesting speculation, particularly in relation to sclerosis of the aortic valves; but it takes us beyond the scope of this article; and of course the traumic lesions under consideration here are met with in all walks of life.

Defects of other valves from strain are improbable, although possible A medical colleague has described to me the development of a bruit during effort, with comparatively little distress subsequently, which is suggestive that the foramen ovale had become patent.

From Direct Violence: It has been proved experimentally in the post-mortem room by a number of observers that heart valves can be ruptured by a blow over the chest wall, which does not produce external injury. In

experimental work on dogs Bright and Beck[20] and Kissane, Fidler, and Koons[18] have recorded valve rupture from a blow. In some accidents external violence and internal stress may act together.

In the type of case to be considered here the presumption is that the valves were healthy, and there is less need to discuss the possibility of antecedent chronic valvular disease. We must realize, however, that in those exceptional patients who survive the event of rupture of a valve from direct violence, some healing will take place, and eventually the physical signs will be indistinguishable from those met with in valvular disease due to natural causes At such a stage the history and past medical evidence is the only guide on which to base the etiology of the valve lesion. This point is illustrated by two examples of my own:[10]

A man of thirty-two years of age joined up at the beginning of the war in 1914, with a previous history of good health and athletic activity. He served a year in the front line In 1915 he was blown up and buried in the debris A day or two later he recovered consciousness to find his heart very distressed There was no external injury. He was five years in one hospital and another. From 1919 until his death in 1937 from pneumonia, he was under my own observation many times It was obvious in 1919 that the mitral valve was diseased, there being a systolic bruit and a localized mid-diastolic sound. Five years after the injury he could sit out of bed and he improved gradually. By 1930 (fifteen years after the injury) the physical signs were indistinguishable from those of mitral stenosis of rheumatic origin There was a presystolic thrill and bruit localized to the mitral area His condition remained stationary. When he died from pneumonia twenty-two years after the injury the stenosis was obvious and there were features which confirmed beyond doubt the diagnosis of trauma.

The evidence is conclusive that the mitral valve was normal before the trauma At a stage when the clinical features were typical of mitral stenosis the trauma could only be recognized through the detailed history.

By way of contrast I have the following record:[6]

At a coroner's autopsy in 1937, at the Derby City Hospital, I was present when Dr Osborn demonstrated disease of the aortic valves very suggestive of being the result of trauma There was an old fracture of the sternum over the base of the heart The man was wounded in the leg during the war in 1916, when a front line soldier, so that presumably his heart was normal Whilst he was in a casualty clearing station, the sternum was fractured by a fall of roof in an air raid, after which he was invalided out of the service. The history is so fragmentary that it is not possible to make a definite diagnosis of traumatic disease of the aortic valves, but it is the most probable explanation. The aorta itself was particularly healthy, as also was the mitral valve

The case was accepted as death resulting from war service, but, scientifically, it is not proved in the absence of any records which help to assess the heart condition soon after the fracture of the sternum

Kissane, Koons, and Fidler[19] reported a case of rupture of the aortic valves in a man who was buried by an explosion. The sternum was fractured and there was a crushing sensation in the chest, with dyspnea as soon as consciousness was regained. He lived for rather more than a year when the aortic lesion was confirmed at autopsy. Two cases reported by Kissane[16] as contusion of the heart showed evidence of damage to the

mitral valve. Wilks[76] recorded the case of a young man who fell from a height, striking his left side on a stone. He died two days later from peritonitis due to a ruptured bowel. Dyspnea had been present, "but a stethoscope was not used." No external bruising was seen. At necropsy the posterior cusp of the aortic valves was split transversely, but there was no sign of chronic disease of the valves. A small deposit of fibrin was found on the rugged edges of the valve. Gibson[29] recorded a case in the Edinburgh Royal Infirmary of rupture of the mitral valve from the kick of a horse.

A sufficient number of similar clinical and pathological findings has been recorded to make this type of valvular lesion a well recognized clinical entity. There may be no evidences of external injury. The immediate symptoms may be somewhat masked by the blow or other injuries, but early distress and signs of a valvular lesion will establish the diagnosis.

Bright and Beck[20] observed bruising of the interventricular septum in postmortem examinations following trauma. East[26] described the case of a young man nineteen years of age who received a severe bump on the chest from his steering-wheel in a collision. He had been examined and passed by a medical board for the Royal Air Force three months previously Just after the accident no signs of heart disease were present, but examination about fourteen days later revealed a rough systolic bruit and thrill, most intense in the fourth space on the left of the sternum. He was free from symptoms. Three and a half years later he had no symptoms but the bruit and thrill were unchanged. Screening showed a normal left auricle. On this evidence a traumatic rupture of the interventricular septum was diagnosed The writer has been told of a somewhat similar case in which the efficiency of the heart was good although an obvious systolic bruit developed after a thoracic injury. Rupture of the septum is a possible explanation of Anderson's[4] case in which the bruit persisted, although the efficiency of the heart was restored. Pollock[53] recorded an example of ruptured interventricular septum, with clinical features of systolic bruit and thrill, following a steering-wheel accident The diagnosis was confirmed at autopsy.

A more difficult problem is to assess the significance of a history of direct trauma to the chest wall as an etiological factor in a particular case of valvular disease of the heart. The well-known facts that rheumatic infection may be present with little or no history of its advent and that the aortic valves will become sclerosed from continued strain, lead us to accept without question that most cases of valvular disease are due to natural causes. Allbutt,[2] however, described two cases of mitral stenosis in young men, in one case due to the kick of a horse and in the other to a blow with a cricket ball. The immediate distress at the time was alarming, but the heart's function was not distressed soon afterwards to a degree that would indicate rupture of a valve. Allbutt saw each patient about a year after the blow and found definite evidence of mitral stenosis, which he attributed to trauma. Sigler[66] examined a man thirty-nine years of age five months after a crushing injury of the chest. The chief complaint was angina of effort. Sigler could detect some degree of aortic incompetence,

but a year subsequently the signs were more pronounced. Judging by analogy from the proved cases of rupture of a valve, it is clear that a blow might produce a contusion with hemorrhage or small tear in a valve which on healing would progress towards chronic valvular disease. Where the evidence seems reasonably convincing, the diagnosis is justified.

CONTUSION OF THE HEART

Pericarditis: A *pericardial friction* sound following trauma is a well-recognized sign, but it is not met with frequently and its significance must be assessed in association with other conditions. It may appear some days after the injury and tends to be evanescent, which features have been in evidence in two of my patients and in the case recorded by Smith and McKeown.[67]

Warburg's[71] series of nonpenetrating heart injuries contained four cases of *purulent pericarditis*. All ended fatally. The introduction of penicillin may improve the prognosis.

Hemopericardium is the most important pericardial complication of heart contusion. A small amount is probably common, but a considerable quantity may lead to heart tamponade with full veins in the neck and the signs of shock. (See Wounds of the Heart.) Radiology will confirm the diagnosis. Moullin[54] described the condition in a youth from a blow over the sternum. He incised the pericardium on the twenty-fifth day, after which recovery was complete. Rajasingham[64] met with a case of a young woman with hemopericardium following a blow with a fist; a small amount was aspirated but most of it absorbed naturally. Bright and Beck[20] found records of seventy-six cases of heart rupture with death from heart tamponade. In view of this evidence the question of surgical interference in hemopericardium as the result of trauma must be seriously considered.

Pneumopericardium has been described with loss of cardiac dulness and splashing sound or bruit de moulin Three examples were reported by Kern and Godfrey[45] as the result of war injuries. But Nixon pointed out that in chest injuries such signs may be fallacious.

Angina Pectoris and Coronary Thrombosis: There are numerous references in medical literature to angina pectoris following a blow over the chest. In most cases there are disposing causes of age and arterial degeneration. White in 1937 states that fatigue of nervous type may dispose towards angina. This may be an added factor when litigation is impending. Beck[13] and Kissane[46] described the syndrome in cases recorded as contusions of the heart. For convenience angina pectoris following chest injury may be discussed under the heading of contusion of the heart, but there may not in all cases be structural damage. Lewis[52] wrote, "Angina pectoris and cardiac failure never can find equivalents in the terms of structure."

As an example of angina of effort the result of direct injury to the chest wall, the following recorded case[6] is significant because there is no question of compensation. The diagnosis is based on what the man himself and his doctor can tell us:

A railway clerk, aged fifty-four years, has always had good health On June 4, 1937, he tried to jump on to the rear of a lorry, which moved. He fell heavily onto his left side, sustaining a cut head and bruised elbow and hip, and "his ribs were sore" There was no immediate discomfort apart from the bruising, but a fortnight later, when recovering from this, he noticed that when walking briskly for an omnibus he got a gripping pain in the chest, radiating down the left arm, and he had to stop This discomfort became more frequent and occurred on slight exertion, such as climbing stairs; so that after doing a fortnight's work he gave it up The heart was recorded as irregular and the rate unduly increased on exertion In August the attacks were less severe, but they persisted. The pulse was regular. He improved, but in December would still get angina with moderate exertion On December 7th, seen by myself, the heart showed no abnormal signs, and an electrocardiogram was normal. The exercise tolerance was rather poor, but he was proposing to go back to his duties which were clerical. He did not feel capable of working in his garden

In the summer of 1938 he was playing cricket in a village team and was in good health six years later

A history such as this may be taken as proof that the angina was the result of trauma; very possibly associated with a myocardial bruise In many instances, however, following chest injury, angina of effort has tended to persist and there has been reason to suspect coronary artery disease. It was described by Blackall[16] as the result of a carriage accident but seems to have had little consideration until comparatively recent times, perhaps because modern traffic and mechanized industry have increased the liability to accident.

Although we are considering in this article structural cardiac damage which results from injury, it must be admitted that such lesions are comparatively rare. In a disease so common as angina one must keep an open mind. It is well to remember, however, that elderly men may require care and attention after injury, lest their health deteriorates and angina develops. They should not be dismissed from a hospital casualty department without advice, just because no bones are broken. Heberden said of angina, "It is increased by disturbance of the mind."

A true coronary thrombosis as the result of bruising of the myocardium is a reasonable possibility. There are well-authenticated examples cited by Wearn,[73] Beck,[13] Kissane,[46] Warburg,[71] Campbell,[23] and Sigler.[66] The interval between the injury and the typical seizure has usually been a few days.

It seems most improbable that exertion or an intense strain should cause a coronary thrombosis although the writer has seen one suggestive case. Boas,[17] however, claims to have met with twenty-five examples. The art of history-taking must be considered. It is quite common for a man of good health, who develops a pain, to believe that he must have strained himself in his garden or at work It is his explanation of the unusual feature. In the analysis of the histories of 555 patients with coronary thrombosis made by Master, Dack, and Jaffe[53] there were in all more than 800 seizures. They concluded that the attacks occurred "irrespective of rest, activity, excitement, or emotion." In assessing the possibility of some precipitating cause this evidence should be borne in mind.

Sudden Death: A rare but well-known occurrence is fatal syncope following a blow over the heart, without there being any abnormality detectable at autopsy. (See Ventricular Fibrillation.)

Myocardial Injury: The accidents which are known to have caused rupture of the heart, or a serious myocardial contusion, have been a blow over the front of the chest, including a fall from a height, and crushing injuries of the thorax. It is important to realize that there may be no external bruising, nor fracture of the bones of the thorax, particularly in the young with elastic chest wall. And the posterior aspect of the heart may be injured against the vertebral column. Absence of thoracic injury is noted in several histories in this chapter and in addition, Bilderdeck[15] in an adult, and Hamilton[34] in a child, have recorded traumatic rupture of the heart immediately fatal without external injury.

Heart Rupture: Rupture of the heart is of little clinical significance, unless perhaps the picture of heart tamponade might be a justification for surgery with intent to repair the damage. The recorded evidence shows that any one of the four chambers may be ruptured in about equal frequency. A traumatic rupture could hardly be confused with spontaneous rupture of which Goodall and Weir[30] analyzed eighteen examples, in only four of which was there evidence of emotion or strain.

Delayed rupture of the heart, the result of injury, is a rare event but of considerable interest. Groom[32] was called to a boy sixteen years of age, who had collapsed while walking, and found him dead. A month previously the shaft of a pony trap had pressed him against some railings. He was in bed five days, but there was no external bruising. Postmortem, the left ventricle was ruptured posteriorly. It appeared that the lesion had developed from the endocardium outwards. Gunewardene's[33] case was of a boy aged nine years whose chest was crushed, without apparent harm, but ten days later he died on the playground from rupture of the left ventricle. There are records of some fifteen or so such cases of delayed rupture. O'Neill[57] described one on the forty-seventh day; Priest[62] on the second day, from a cricket ball. And Tuohy and Boman[68] reported this event in a man sixty-three years of age two weeks after a steering-wheel accident.

It seems probable that the primary injury is a tear in the endocardium. French[27] and Hawkes[35] recorded rupture of an aneurysm of the left ventricle following injury. Both were children and in the one case rupture took place on the twenty-first day and in the other three months after the accident. These two examples prove the possibility of an endocardial tear and illustrate how a cardiac aneurysm might develop.

Contusion of the Myocardium: White[74] stated that contusion of the myocardium is probably fairly common and recovery the rule. Evidence from the coroner's postmortem room, in accidents which have proved fatal from head or other injuries, has revealed myocardial contusions compatible with recovery and which might have caused no symptoms. When the writer took a routine electrocardiogram[9] on a series of seventy-five patients with chest injury, there were several with temporary abnormalities suggesting myocardial lesion in whom there were no symptoms.

On the other hand patients in the accident wards with fractures of the bones of the thorax or with contusion of the lungs, hemothorax, or pneumothorax, will have symptoms which may mask those which might arise from myocardial injury. Furthermore rest in bed, which such injuries may entail, could keep in check symptoms referable to the heart.

The history of an uncomplicated myocardial contusion such as that recorded by the writer[7] and by Lee, Usher, and Houck[51] may be divided into (1) the accident, (2) an interval, (3) an urgent attack of dyspnea, (4) gradual recovery as a rule with rest in bed, and (5) complete recovery in a favorable case, when the heart was not previously diseased. Particular stress should be laid upon the interval between the immediate reaction to the accident and the appearance of symptoms referable to the heart. It is usually about twelve hours but may be delayed for several days.

The characteristic symptoms are a little frothy expectoration; there is dyspnea with orthopnea, a feeling of faintness with precordial pain and discomfort. The blood pressure is low, the pulse rate variable. The electrocardiographic changes are somewhat similar to those of coronary occlusion, or there may be flat or inverted T waves, T waves of exaggerated amplitude, large Q waves and slurring or notching of the QRS complex. These signs must be sought within a day or two of the accident because they may soon pass off.

The two following clinical histories from my own observation are of interest:

CASE 1: A lorry driver, aged forty years, with excellent health, was lifting large blocks of limestone into the lorry One stone broke, and a large piece struck him on the front of the chest and knocked him backwards He felt a sharp "stitch" above his left nipple, but there was no outward injury. He ceased loading and rested a short time, but felt quite well and drove the lorry for several hours. He went to bed apparently all right, but woke up with precordial pain, dyspnea, a cold sweat, and his legs felt numb. His doctor was called but only recognized a rather weak but regular pulse He remained in bed or his room for about seven weeks, with at first some pain and discomfort in his left side Seen by me two months after the accident, a full investigation revealed no abnormalities He still complained of a feeling of weight in the left side of his chest and of some inability to exert himself His exercise tolerance, tested by climbing stairs, was poor He was at work a month later and perfectly well six years subsequently

CASE 2 A sailor, twenty-two years of age, about midnight was knocked down by a lorry, and a loaded trailer passed over his back as he lay on his face. He was admitted to hospital showing little distress, with no signs of chest injury The pulse rate was 100 and regular The respiration rate was thirty but there was no obvious distress Three hours later the respiration rate was 40, the pulse rate 120 and he began to bring up large quantities of frothy serum He died four hours after the accident At autopsy there was a crack in the second left rib. There was acute pulmonary edema There was a large myocardial bruise extending deep into the left ventricle, but no rupture or other damage[11]

The diagnosis of a traumatic myocardial lesion may be attended with some difficulty. The heart may be seriously damaged and yet give rise to little in the way of symptoms, particularly if the primary lesion is a tear in the endocardium.

Evidence obtained from the electrocardiogram is very valuable, but a pneumothorax or other chest condition may distort the tracing.

Complications of Myocardial Contusion: Hemopericardium has been discussed. Acute dilatation is common in animal experiments, but there is only one clinical record, which is that of a soldier, twenty-six years of age.[28] Ten days after a severe blow over the chest a large heart was recognized and there was a fatal termination in six months' time.

Valve rupture, or septal injuries, have been discussed. As also forms of arrhythmia.

Traumatic heart block, of course, is a contusion or partial rupture of the conducting bundle. Coronary thrombosis is an exceptional complication.

Sequels of Myocardial Contusion: Cardiac aneurysm is a rare but recognized sequel. Hildebrandt,[37] Joachim and Mays,[40] and O'Farrell[56] have recorded examples. As already stated, this lesion is closely allied to that which may lead to delayed rupture.

Angina of effort is a troublesome sequel but has been discussed in a separate section.

There remains for consideration the question of *persistent functional incapacity* of the heart following a chest injury. Most of the proved cases of myocardial contusion in those who appear to have healthy coronary arteries make a complete recovery, if they survive the initial injuries. In my own experience, however, I have met with several men[6,9] who have been short of breath and dizzy, especially on stooping, ever after a severe chest injury. The condition has resembled the myocardial weakness of the senile heart, although two were under forty years of age. There has been none of the symptoms of a neurosis. At rest or on moderate exertion there is no complaint but the response to exertion is poor. Beck[13] described a case and physician colleagues of mine from several other areas, have told me of similar patients. There is evidence to suggest that a persistent myocardial weakness may result from chest injury, but the condition merits further study. Enig and Rud[78] record several examples of this sequel which they conclude is a neurosis; but their patients showed obvious evidence of nervousness.

The *treatment* of contusion of the heart is chiefly confined to a judicious assessment of the amount of rest indicated. The clinical evidence that rupture has been common in the second week is important. Hedinger[81] recorded a fatal termination from a contusion of the left ventricle on the ninth day and McGill[82] a similar fatality on the eleventh day. If the electrocardiogram gives convincing evidence of myocardial injury, a rest of six weeks is indicated. Bright and Beck[20] were of the opinion that the sudden collapse of rupture into the pericardium might be met by operation and suture; although they admit that hemorrhage into the pericardium following a contusion of the heart is not always fatal. If there is evidence that the action of the heart is hampered from compression of hemopericardium (see Wounds of the Heart) aspiration or surgery may be considered.

WOUNDS OF THE HEART

Wounds of the heart are caused by needles, cutting instruments and firearms. In civilian life they are met with most frequently in countries where the use of the knife is common. For clinical purposes wounds may be divided into two varieties:

(1) Those in which there is free communication between the pericardium and the pleural cavity or the outside. In such cases, death usually supervenes quickly and the only symptoms and signs are those of loss of blood.

(2) Wounds which give rise to accumulation of blood in the pericardial sac causing compression of the heart. This may result from a wound which penetrates the heart or from a divided coronary artery. The symptoms of compression, or heart tamponade, are. Shock out of proportion to the loss of blood, a low blood pressure and pulse pressure, with tendency to slow pulse. A cold dusky skin with sweating. The external jugular veins are distended; which has significance when the head is elevated. The heart sounds are distant and indistanct. With air and blood in the pericardium there will be a splashing sound. The electrocardiograph may not help in diagnosis, although *after* an operation in which a coronary artery has been ligatured, it gives a characteristic picture. There is no pain in this event, however. Occasionally with a pericardium filling slowly radiology may help in the diagnosis. Aspiration of blood from the pericardium may help in diagnosis.

In *treatment* immediate operation is the modern method, and indeed was recommended by Beck[12] and by Bigger and Porter[14] and Bullock.[21] There is now a sufficient number of successes recorded. Farringer and Carr[79] and Griswold and Dryce[80] are among these.

(3) Foreign bodies inside the heart or in the heart wall present a difficult surgical problem. With modern technic, such cases are amenable to surgery, but there is evidence that in a number of cases a foreign body in the myocardium may become encysted in the ventricular wall, causing little inconvenience Of this event Turner[69] reported an example of a patient still alive and quite active twenty-three years after a machine-gun bullet had become embedded in the wall of the left ventricle. Burgess[22] recorded a similar case, in which, however, after six years' freedom from any discomfort, symptoms of distress developed and the bullet was removed surgically.

PRIMARY CARDIAC OVERSTRAIN

There is some diversity of opinion, amongst those best qualified to express it, as to whether the normal heart can be strained. Let us define the normal heart, as one that is efficient for the age and usual activities of an individual, and one which would show no abnormality on examination with all the methods at our disposal Price[61] defined primary cardiac overstrain, as a cardiac disorder which is the immediate result of excessive or injudicious physical exertion in an individual whose heart was previously normal.

In a chapter devoted to the subject of trauma of the heart it will be sufficient to confine ourselves to one form of overstrain, which is the

intense unexpected effort, for which a man is not trained, and during which the chest is probably fixed, with the glottis closed. Typical examples in everyday life are, a heavy lifting effort or the cranking of a heavy and cold motorcar. Sometimes there is impending disaster if the effort should fail, so that fear and excitement may arise. The following note[6] is a typical example.

A man, aged thirty, was carrying a bag of cement weighing two hundredweight across a stream. His foot slipped, and he made a very considerable effort to save the bag from falling into the stream, which would have ruined the cement He had acute distress in the left side of his chest and collapsed on the ground This was in the middle of the morning. He went on doing light work all day, suffering from palpitation and shortness of breath He walked home, a mile or two, very slowly with his father, for whom he worked He went to bed and passed a restless night His doctor kept him in bed three or four days, after which he got about a little. The papitation and shortness of breath continued to some extent for two years Physical examination at this time showed a pulse rate of about 100 when out of bed, with occasional ventricular extrasystoles after resting from exertion, to which there was poor response He was of good athletic physique Before the event in question he was in excellent health He served four years in the war, during which time he won a three-mile race without discomfort

My own experience would not suggest that this type of history and sequence is of frequent occurrence. Allbutt[1] believed that overstress of effort might end in strain, but he taught that for one disability due to strain there are fifty of secondary and incidental derangement. On clinical evidence he believed that the heart muscle might suffer from *dilatation* during exceptional effort with subsequent ill effects; sometimes temporary and occasionally more or less permanent.

Since that time fluoroscopic examination has proved that the "irritable," inefficient heart which is the sequel of strain, real or alleged, is not dilated, but is of normal size But the anatomy of the heart after the event is of less significance than its function. In considering the structure of the heart during the effort, we may bear in mind the observations of Lewis in 1932, that when the heart is examined under the x-ray screen, with inspiration held and the glottis closed, it is seen to dilate greatly. There was abundant evidence that healthy men could perform this test with impunity. But although this may be physiological dilatation, it might proceed to pathological injury of either structure or function during exceptional circumstances.

It is outside the scope of this chapter to discuss the heart reserves in relation to athletic events. But it is a reasonable premise to the subject under discussion here, to say that in athletic event the heart is the part least likely to break down, and strain in athletes is almost confined to those taking part when suffering from some infection. White in 1937 stated that heart symptoms or signs that follow industrial strain or accidents are usually of the neurocirculatory asthenia type, or are due to aggravation of heart trouble already existing. This is in agreement with Allbutt's teaching a generation ago. We are faced with the necessity, however, of trying to assess the significance of the sequence of events which

may result from a short intensive effort in the average man. Donahue[25] in an article entitled, "Accidents and Heart Disease from the Courts' Point of View," wrote: "We do have a great many cases of dilatation of the heart occurring at work while the employee is under some particular strain. He is lifting some unusually heavy load, or is in rather an awkward position doing heavy lifting, when he has dilatation and becomes sick, sometimes collapsing immediately." The events are as described whether or not we accept dilatation of the heart as the explanation. And, of course, a history exactly similar may be obtained from an effort unrelated to industry. When the patient comes under observation later, he complains of some palpitation and restlessness, particularly at night, but chiefly of shortness of breath on ordinary exertion. The exercise tolerance is poor. There may be premature ventricular contraction. A fluoroscopic examination reveals a heart normal in size.

There are three reasonable explanations:

(1) That he is suffering from the effort syndrome, or neurocirculatory asthenia, and the alleged strain has drawn attention to the disability. As confirmation of this we should expect that the capacity for exertion would be variable from day to day, and there might be evidences of anxiety neuroses. Sighing is common and characteristic. There may be complaint of general weakness. In typical examples the effort alleged to have produced the condition will not have been an exceptional one. It is usually taught, however, that the effort syndrome occasionally may follow some exceptional physical effort; and also that in spite of the wisest of treatment, some of the subjects must be warned that they are unsuited for strenuous callings.

(2) That he has torn some fibers of the pectoral muscle or strained a costochondral junction, to which is added a cardiac neurosis. This explanation is given prominence by some of those who hold the view that the normal heart cannot suffer as the result of strain. One example[6] characteristic of rupture of pectoral muscle fibers was free from cardiac symptoms, the only complaint being persistent pain, worse on certain movements for three or four weeks. Perhaps if the heart's action had been disturbed as the result of an associated neurosis, the diagnosis would have been more difficult. But pain which persists is unusual after short intensive efforts. Moreover, it must be remembered that the type of effort may be one quite unrelated to any chest muscles.

(3) That there has been some definite strain of the heart muscle, which has disturbed the function of the heart. The feature most characteristic of a genuine myocardial weakness is a consistent nonvarying degree of disability at any particular stage. There are no symptoms except on exertion. The history of the particular strain alleged and the evidence of any witnesses is of value. The past medical history, including the evidence of his own doctor, is an important guide. That a normal heart should suffer as the direct result of a short intensive effort is an exceptional event, but if all the evidence is carefully assessed it seems probable occasionally.

As the sequence of a short intensive effort with the chest fixed and the glottis closed, it is probable that sometimes the effort syndrome may

result, sometimes there may be rupture of pectoral muscle fibers with a cardiac neurosis added, but sometimes there may be a genuine overstrain of the heart.

Management and Treatment: Whatever diversity of opinion there may be with regard to the diagnosis of the condition there can be agreement with regard to treatment. With a history of some exceptional effort, a short rest is indicated. There should be reassurance that there is no danger to life, and that the outlook is favorable. If the opinion has been communicated to the patient that there has been dilatation of the heart, it is important to have a fluoroscopic examination at once, to assure him that it is of normal size. It is important to explain to the patient that any pain complained of is not cardiac in origin. After a complete examination it is necessary to institute a carefully graded convalescence. In those industries where there is a medical adviser to the firm he should share in this management of the problem. There is a genuine disability whatever be the cause.

TRAUMA OF THE HEART AND COMPENSATION

In the preceding paragraphs the endeavor has been made to discuss trauma of the heart without reference to compensation liability. In this way the evidence may be criticized closely, but with an open mind uncommitted by prejudgment.

As a guide in compensation problems, let us summarize what is proved beyond doubt. Both direct violence and strain of effort may lead to auricular fibrillation or to valvular injury. If the event changes the life history of the patient we are absolved, in the main, from deciding the problem as to whether disease was already existing.

There is considerable recorded evidence of contusion of the heart after a blow on the chest; but diagnosis is obscure, and a sequel suggesting myocardial weakness may present a problem difficult to assess. When, following some chest trauma, angina of effort persists in an elderly man, it is by no means easy to estimate the relation to accident.

The most vexed question is whether there may be genuine primary cardiac overstrain following a short intensive effort. Let us regard this as a rare and exceptional event, but one which may sometimes change a man's life history, although probably only for a time. The indication is to give a good prognosis, with early return to work, such as he is able to do. It is usually in the best interests of all concerned to avoid the division of opinion which litigation encourages; because with a definite history of exceptional effort and a heart disturbed in function, the disability is a real one.

Those heart lesions of which there are only a few recorded examples following trauma, must be considered carefully as individual problems.

REFERENCES

1. Allbutt, C.: "A System of Medicine," Vol. 6, p 424, The Macmillan Co, London, 1909.
2. Allbutt, C.: Tr. Clin Soc. London 6:101, 1873
3. Allbutt, C: St. George's Hosp Rep. 5:23, 1870

4 Anderson, R G: Brit M. J. 2.307, 1940
5 Arenberg, H · Ann Int Med 19 326, 1943.
6. Barber, H: Brit. M. J 1:433, 1938
7. Barber, H.: *Ibid.* 2:520, 1940
8 Barber, H.: Brit Heart J 4 83, 1942
9 Barber, H.. Quart J Med. 52 137, 1944
10. Barber, H, and Osborn, G R: Guy's Hosp. Rep 87 510, 1937
11 Barber, H, and Osborn, G R Brit. Heart J. 3 127, 1941
12 Beck, C. S: Arch Surg 13:205, 1926
13 Beck, C. S.: J A M.A. 104:109, 1935.
14 Bigger, I A., and Porter, W B: Internat Clin 1 132, 1931
15. Bilderbeck, A C L.· Brit. M J 1 675, 1919
16 Blackall, J: Observations on the Nature and Cure of Dropsies, p 373, London, 1813
17. Boas, E. P.· J A M.A 112 1887, 1939
18 Brahdy, L., and Kahn, S Trauma and Disease, 2nd ed 34 6, New York, 1941
19 Bramwell, C · Lancet 1:8, 1934
20 Bright, E. F., and Beck, C S Am. Heart J 10·293, 1935
21 Bullock, W. O: Ann. Surg 103 696, 1936
22 Burges, A H: *Ibid* 100 111, 1934
23 Campbell, M: Brit. Heart J 1 177, 1939
24 Coffen, T. H · Am Heart J 5 667, 1930
25 Donahue, Commissioner F J Am Heart J 3 532, 1927
26. East, T: Brit. Heart J 3 116, 1945
27 French, H.: Guy's Hosp. Rep 66 349, 1912
28. Froment, R Camelin, and Blanchard, H Presse Med 49 111, 1941
29 Gibson, G A · System of Medicine Ed Allbutt and Rolleston 6 381, 1909
30. Goodall, J S, and Weir, H B: Brit. M J. 1 834, 1927
31 Gordon, W.: Practitioner 109 223, 1922
32 Groom, W: Lancet 1 1202, 1897
33 Gunewardene, H O Brit M J 2 942, 1934
34. Hamilton, J. A Brit M J 2 1101, 1934
35 Hawkes, S Z · Am. J Surg 27: 503, 1935
36. Hay, J, and Jones, H W Brit, M J 1 559, 1927
37 Hildebrant, F Beitr z Aet d Herz Diss Berlin, 1898
38 Horton-Smith, P Clin J 19 252, 1902
39 Howard, C P Canad M A J 1912, 1928
40. Joachim, H, and Mays, A T · Am Heart J 2 682, 1926-7
41 Jokl, E *The Medical Aspect of Boxing, Pretoria 54 6, 1941*
42. Kahn, M H Am J M Sc 179 605, 1930
43 Kahn, M H, and Kahn, S Am. Heart J 3 546, 1927-8
44 Kahn, M H, and Kahn, S Ann Int. Med 2 1013, 1929
45 Kern, R A, and Godfrey, E. W: U S Nav M Bull 4 1001, 1943
46. Kissane, R W. "Contusion of the Heart," Ohio State University, Columbus, 1937.
47 Kissane, R. W, and Koons, R A Ohio State M J 34 303, 1938
48 Kissane, R. W., Fidler, R S, and Koons, R A Science Press 13·170, 1940
49 Kissane, R W., Koons, R A, and Fidler, R S. Am Heart J 12 231, 1936
50 Kissane, R W, Koons, R A, and Fidler, R S · Ann Int Med 11·907, 1937-8
51 Lee, R V, Ussher, N T, and Houck, G H Am J M Sc 206·722, 1943
52. Lewis, T: "Diseases of the Heart," The Macmillan Co, London, 1937
53 Master, A M, Dack, S, and Jaffe, H L J A M A 109 546, 1937
54 Moullin, C. W. M Lancet 1.314, 1897

55. Nixon, J A.: Brit M J. 2 24, 1941.
56 O'Farrell, P. T.: Brit Heart J. 1·172, 1939.
57 O'Neill, B J: J A M A 62:697, 1914
58 Osborn, G R Lancet 2 277, 1943
59 Peacock, T B: "Valvular Disease of the Heart" (Croonian Lecture) 1865a.
60 Peacock, T B: Tr Path Soc. London 16:67, 1865b.
61. Price, F. W · "Textbook of the Practice of Medicine," 5th ed, London, 1937.
62 Priest, R.· J. Roy Army M. Corps 73·125, 1939.
63 "Queries and Minor Notes" J A M A 100:1558, 1933.
64 Rajasingham, A S: Brit. Heart J 1 181, 1939.
65 Schlomka, G Ergebn d inn Med u. Kindern 47:1, 1934
66. Sigler, L. H J.A.M A. 119 855, 1942.
67. Smith, L B, and McKeown, H J Am. Heart J 17:561, 1939
68 Tuohy, E L, and Boman, P G: Ann Int Med. 4 1373, 1931
69 Turner, G G: Lancet 2 487, 1940
70 Walker, G F, and others "The Injured Workman," John Wright and Sons, Ltd, Bristol, 1933.
71 Warburg, E · "Subacute and Chronic Pericardial and Myocardial Lesions Due to Non-penetrating Traumatic Injuries," Copenhagen, 1938
72 Warburg, E · Brit. Heart J. 2.271, 1940.
73. Wearn, J T.· J A M A 104 114, 1935
74 White, P. D · "Heart Disease," The Macmillan Co, New York, 1944.
75 White, P. D, and Glendy, R E "Trauma and Disease," 2nd ed Ed Brahdy, L, and Kahn, S, New York, 1941.
76. Wilks, S: Tr Path Soc London 16.77, 1865
77 Wood, P Lancet 2 796, 1937
78 Enig, R, and Rud, E Act Med Scand 146·393, 1953
79 Farringer, J L, and Carr, D.: Am J Surg. 85 747, 1953.
80 Griswold, R A, and Dryce, J C · Ann. Surg 139.783, 1954.
81 Hedinger, C, and Cardiologa, Basel 12 46, 1948
82 McGill, R J Lancet 1 997, 1952.
83 Pollock, B. E, et al Am Heart J 43 273, 1952
84 Goldman, L, Bick. Was Med 2 279, 1941-2

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37

Shock

Introduction: The nature of shock is a subject which has been confused by an attempt to bring within one category all conditions characterized by a low blood pressure. This attempt was natural since one of the outstanding accompaniments of shock is the low and falling blood pressure. Cannon[1] has stated that "low pressure is probably the central feature, or one of the most essential features, of shock." With the paramount importance of diminished blood pressure in mind, classifications were made to differentiate the various types. Shock was defined in terms of primary and secondary shock on the basis of the time of its onset. Others defined shock in terms of the initiating causes, such as histamine shock, shock from burns, shock from peritonitis and traumatic and surgical shock. In one of the more complete classifications recently brought forward, Harrison[2] has classified shock under the terms, hematogenic, neurogenic and vasogenic. These classifications have an assumption in common, namely that shock is essentially a condition of low blood pressure. The issue is confused if shock is more than a state of lowered arterial pressure. It is necessary to recall the classical picture of shock in order to ascertain whether or not there is more of significance than the reduced blood pressure.

The patient in shock has the appearance of being seriously ill. The significant features are centered about the peripheral circulation. The skin is cold and moist. The pulse is feeble and rapid. There is usually a lowered blood pressure and the patient presents the picture of weakness bordering on exhaustion. This condition is not sudden in onset but requires time for its development If untreated, there is a steady decline to a fatal termination. During the downward course, there is progressive enfeeblement and gradual suppression of all the bodily functions. With this picture in mind, it is clear that low blood pressure is not the only feature of significance. There is the time factor. Low pressure itself is not necessarily fatal but if the reduced blood pressure is maintained for a period of time, shock may be produced. Again, the progress of the shock is of significance Shock cannot be diagnosed simply by a single determination of blood pressure. It is the course of the blood pressure rather than the isolated reading which is important. Shock will therefore be defined in terms to indicate that it is a process rather than a static condition.

Definition: *Shock is the clinical condition characterized by progressive loss of circulating blood volume brought about by the tissue anoxia which results from inadequate circulation.*

In this definition, which is illustrated in Fig. 1, there are four points which require discussion: The reduced blood volume, the progressive nature of the loss, the tissue anoxia, and the inadequacy of the circulation.

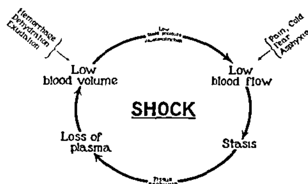


FIGURE 1. The process of shock. (Freeman: Pennsylvania M. J.)

Is There Always a Diminished Blood Volume in Shock? The brilliant researches of Robertson and Bock[3] and Keith[4] during World War I showed clearly that a reduced blood volume was the cause for the reduced blood pressure in shock. It is generally agreed today that there is a reduction of the circulating blood volume in shock.

Is the Loss of Circulating Blood Volume Progressive? Hemoconcentration in the process of shock was first described by Cannon, Fraser and Hooper.[5] This concentration is more evident in the peripheral regions than in the central circulation. Studies by Moon[6] have supported the earlier observations. There is general agreement on the significance of progressive hemoconcentration as shock is developing. This concentration indicates loss of plasma volume.

Is There Tissue Anoxia in Shock? One of the characteristic observations on clinical cases of shock, has been the subnormal temperature. Studies of the oxygen utilization in experimental animals during the process of shock[7] have demonstrated a serious reduction in the bodily metabolism. Direct study of tissue anoxia has not been made but the inferences drawn from examination of the blood are suggestive. Acidosis is well recognized as a feature of shock. It is considered to be an expression of the tissue anoxia. The reduced oxygen content of the venous blood gives further evidence of the impaired oxygenation of the tissues. This condition was first described by Aub and Cunningham[8] and subsequent studies by Blalock and Bradburn[9] and Freeman, Shaw and Snyder[10] have given support to this concept. Apparently, shock is associated with a severe degree of tissue anoxia.

The precise nature of the changes, physical and chemical, brought about by tissue anoxia, and in what manner these changes produce an increase in permeability of the capillaries, is not known. Certain of the

recognized alterations will be taken up in the discussion of the chemistry of shock.

Is There Reduced Circulation in Shock? The significance of inadequate circulation in shock was clearly stressed by Erlanger, Gesell, and Gasser[11] at the close of World War I. Studies by Gesell[12] on the effect of

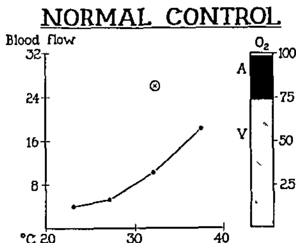


FIGURE 2 Blood flow in normal control In this, as in the following figure, the solid line shows the effect of increasing temperature of hand on blood flow through the hand Cross surrounded by circle indicates blood flow thirty seconds after release of tourniquet which has been applied for five minutes. Column at right indicates oxygen saturation of *A*, the arterial, and *V*, the venous blood, taken from that hand Ordinates—blood flow Abscissae—degrees centigrade (Freeman Pennsylvania M J)

hemorrhage and tissue-abuse on peripheral blood flow further strengthened this concept. Investigations illustrated in Figs. 2 and 3 on the peripheral blood flow through the hand in clinical cases of surgical shock by Freeman, Shaw, and Snyder[10] suggested the etiological significance of inadequate circulation in the production of shock. Blalock and Levy[13] observed that the circulation was reduced although not to as great a degree, in other regions of the body in this condition. Investigations in the laboratory have thus confirmed observations in the clinic that there is a serious reduction in the distribution of blood to the tissues of the body during the course of shock.

Clinical Picture: The clinical picture of shock is determined by two considerations: (1) The physiological responses of the body to the initiating causes and (2) The bodily reactions to failure of the circulation.

1. The initiating causes of shock are traumatic, in the broad sense. They subject the organism to harm or to the prospect of injury. Whether the initiating factor be dehydration, trauma, or emotional distress, there is a threat to the survival of the individual. The sympathetic nervous system, as Cannon[14] has pointed out, is specifically designed to cope with an emergency and is called into play by stimuli which threaten the integrity of the organism Such factors as cold, pain, asphyxia, fear, hem-

orrhage, infection, and dehydration have been found to be strong stimulants of sympathoadrenal activity. In this manner, the original cause of the shocklike condition calls forth activity of the sympathetic nervous system. These evidences of sympathetic activity are to be found in the increased pulse rate, the pallor of the skin, the sweating, the parched throat, and the suppression of gastrointestinal activity.

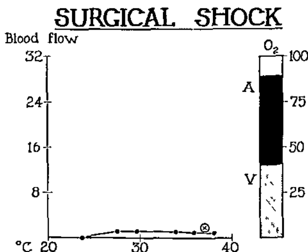


FIGURE 3 Blood flow in surgical shock This patient had been operated upon for intestinal obstruction four hours previously. A cecostomy had been performed under local anesthesia At the time of observation she was in clinical shock, with subnormal temperature, cold, clammy skin, a pulse of poor volume with a rate of 135, and a blood pressure of 80/60 She succumbed in spite of repeated transfusions six hours after these observations were made (Freeman: Pennsylvania M J)

2. As soon as there has been some alteration in the internal environment of the body, as for instance by acute loss of blood from hemorrhage, certain mechanisms are called into play to readjust the organism to the defect. There is acceleration of the pulse and vasoconstriction to maintain the level of the falling blood pressure. The blood is diverted from the nonessential parts of the body, such as the skin and the intestinal tract, to the vital organs. These reactions may be called purposeful in that they are designed to fit the body to meet the emergency. The clinical picture of shock is thus in part an evidence of the reaction which the organism is making to adjust to the changes in its internal environment.

When the stage of failure has been reached, the clinical picture becomes more precise. At this stage, there are combined the evidences of the body's reaction to the initial trauma with evidences of inadequate circulation to the tissues. As a result of general impairment in the supply of blood to the tissues, with consequent tissue anoxia, there is progressive acidosis. With the failure of the peripheral circulation, there is evidence of concentration of the blood in the capillaries and venules. Unless hemorrhage has played a major part, there is usually cyanosis of the skin and mucous membranes. Hemoglobin, hematocrit, or red blood cell de-

termination of the peripheral blood show evidence of concentration of the formed elements. There is suppression of renal function with retention of nitrogenous waste products. Gastrointestinal function is inhibited with resultant distention and paralytic ileus. The progressive reduction of the circulating blood volume leads to a falling blood pressure and a rising pulse rate, the unmistakable signs of shock. Failure of the circulation is associated with cessation of salivary flow and intolerable thirst. The mental faculties gradually become clouded until the patient sinks into stupor which merges imperceptibly with death.

Pathology: Shock is the final phase of many clinical conditions characterized by prolonged impairment of the circulation. The pathological picture of shock is usually complicated by that of the initial lesion which produced the process. In this discussion emphasis will be placed only upon those features which belong essentially to shock.

In his investigations on the mechanism of hemorrhagic infarction, Welch[15] made the significant observation that reduction in the arterial pressure in the mesentery of the dog produced stasis with concentration of the blood corpuscles in the capillaries and veins of the loop of intestine supplied by the artery which was compressed. He could observe no change in the appearance of the vessel walls but found that the forward movement of the blood was checked and that stasis soon took place. Landis,[16] in his observations on the mesentery of the frog, analyzed this reaction more closely and found that, although no changes might be visible in the blood vessel walls, there was an increase in the permeability of the endothelium so that plasma escaped and left the cells stranded. These facts have been confirmed by a number of observers and appear to be well substantiated It is the opinion of the majority of investigators who have worked in the field of shock that this increase in the permeability of the minute blood vessels, in consequence of impaired circulation, is the central feature in the process of shock. The pathological picture which is found when the tissues are examined after death from shock is that to be expected from peripheral circulatory failure. There is widespread congestion and engorgement of the capillaries and venules throughout the body

Such a picture was found by Gasser, Erlanger, and Meek[17] in shock experimentally produced in a variety of ways. They observed in the intestinal mucosa that "the capillaries and small veins are greatly dilated and tightly packed with red blood cells." More recent studies on the pathology of shock by Moon[6] have corroborated their observations. This congestion from stasis is found throughout the viscera and in the lungs. There is edema in the tissue spaces and effusion in the serous cavities. If the impaired circulation has persisted in the experimental animal for sufficient time there may be actual necrosis of the intestinal mucosa[18] as shown in Fig. 4. The ultimate pathological picture of shock may in reality be ascribed to death of the peripheral tissues before that of the body as a whole

Physiology: The physiology of shock is determined by the reactions of the body, not only to the initiating causes, but also to the reduction of

circulating blood volume which represents the underlying feature of shock. For purposes of convenience, these reactions will be grouped under the different organ systems.

Cardiovascular: There is sympathetic stimulation of the cardiovascular system throughout the course of shock, no matter in what manner the

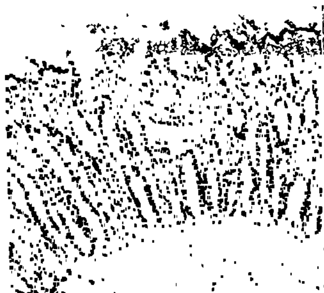


FIGURE 4 Microscopic appearance of the duodenum of a dog in which shock had been produced by low blood pressure of six hours duration brought about by graded hemorrhages The superficial portions of the mucosa had disappeared (Freeman, Shaffer, Schecter, and Holling: J Clin Invest)

process is brought about. This stimulation is to be observed in the increase in pulse rate and the peripheral vasoconstriction. The character of the pulse is of great significance in the clinical estimation of the condition of shock. Its volume probably gives the single best indication of the general condition of the patient. The contrast between a full radial artery which indicates an adequate output of the heart and a weak "thready" pulse of poor volume differentiates a blood pressure associated with a normal cardiac output from an identical blood pressure maintained by peripheral vasoconstriction in the face of a diminished circulating blood volume. Johnson and Blalock[19] have shown that the cardiac output declines well before the blood pressure as shock comes on. It may be said categorically that there is always an increase in pulse rate in shock unless there is direct or reflex cardiac inhibition. Failure in cardiac response may be intrinsic since it has been shown that in experimental[20] and clinical[21] dehydration, there may be such impairment of blood supply to the heart itself that full tachycardia is not observed. The cardiac inhibition may also be reflex through vagal stimulation as in increased intracranial pressure.

Vasoconstriction is also a regular accompaniment of shock. This constriction is more marked in the peripheral portions of the body[10] than in the central areas.[13] In the early stages, particularly in the presence of

fever and infection, the blood flow through the peripheral portions may actually be increased. It seems likely that this hyperemia is due to the vasodilatation which represents the body's effort to dissipate heat. In the later stages of shock, there is always marked peripheral vasoconstriction in spite of an elevated temperature.

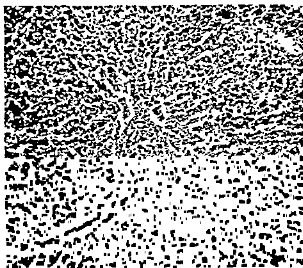


FIGURE 5 Microscopic appearance of the liver of a dog in which shock had been produced by low blood pressure of six hours duration brought about by graded hemorrhages The liver cells showed degeneration and necrosis (Freeman, Shaffer, Schecter, and Holling J Clin Invest)

The blood pressure is generally low in the early stages of shock, especially if there has been loss of blood or plasma. When the condition is being produced without original impairment of the cardiac output, the blood pressure may be normal or even increased. The state of the peripheral circulation is of greater significance than the blood pressure. In the words of a surgeon of wide experience, "I'd rather see pink ears than an elevated blood pressure." In the terminal stages, the blood pressure is always reduced, and the degree of reduction bears a close relationship to the severity of the shock.

Gastrointestinal: Stimulation of the sympathetic nervous system brings about inhibition of function in the gastrointestinal system, and the signs of shock in this system are expectedly those of decreased activity. The salivary flow is suppressed with resultant dry mouth and parched throat. Peristalsis is diminished and paralytic ileus may be produced. The reduction of circulation in the intestinal tract is frequently associated with injury to the mucosa so that superficial ulceration may be found with free blood inside the lumen. There may be injury to the liver from the prolonged anoxia[18] as shown in Fig 5. This damage may give rise to widespread bodily changes Even though the patient may respond well to remedial measures as far as the circulation is concerned, the splanchnic inhibition will frequently present a major complication.

Genitourinary: The reflex vasoconstriction does not spare the kidneys, as the typical suppression of renal function indicates. There is retention of nitrogenous waste products The urine is concentrated and contains albumin, red blood cells and casts although after the patient has recovered, there may be no evidence of permanent renal damage. Occasionally the suppression of renal function may be so severe that anuria results. This anuria may persist long after the patient has recovered from the circulatory crisis.

Neuromuscular: Although there is no impairment of muscle power, the patient in shock exhibits great weakness and prostration. There is a disinclination to move. As the stage of decompensation is reached, the extremities become cold and the muscles feel doughy to the touch. The sensorium is clouded although the individual may be conscious to the end. Reaction to painful stimuli, both in clinical and experimental shock is lessened. The psychic response seems to be one of apathy although on closer observation the apparent lack of interest in the surroundings may be found to be the result of a state of abject terror. The patient is paralyzed with fear. Death is staring him in the face and he cannot look away

There is frequently dilatation of the pupils and there may actually be exophthalmos. The wide-staring eyes, restlessness and "over bright" appearance of the patient with peritonitis are signs which are to be viewed with alarm.

The skin is usually moist and cold and has been termed clammy, to suggest the similarity to the sensation of touching dead flesh. The death of Falstaff is graphically described by Mistress Quickly "then I felt to his knees, and they were as cold as any stone, and so up'ard and up'ard, and all was as cold as any stone." Cyanosis is present in the nail beds and the skin of the abdominal wall may exhibit a blotchy appearance. When the finger tip is pricked to obtain blood for study, there slowly exudes a dark viscous fluid. If an incision be made, the wound does not bleed except for a slow trickle from the veins The blood is dark. The muscles appear brown and desiccated In the splanchnic area the arteries are seen to be contracted to fine threads and the veins show up more prominently as darker ribbons. There seems to be a general loss of tone in the voluntary muscles.

When dehydration is associated with shock, the skin is dry and cyanosis is more apparent. When pinched into a fold the wrinkle will persist. The eyeballs are soft and the eyes sunken in the sockets. The tongue is dry and red and the mucous membrane of the mouth glazed.

Respiration: If hemorrhage has been a major factor in the production of shock, the respiration is generally of the sighing type with occasional deep yawns Otherwise, the breathing is frequently suppressed both in depth and frequency. As the later stages of shock approach, with the attendant acidosis, the respiration is increased and may be quite rapid. In the terminal stages, the respiratory center is more and more depressed until the breathing finally ceases.

Chemistry: No chemical substance capable of producing shock has yet been consistently demonstrated in the circulating blood in sufficient quantity to be generally accepted as the cause of shock. There are many substances, on the other hand, which can produce shock when injected into the blood stream. Histamine, peptone, muscle extract, intestinal contents, and many other substances will produce shock on intravenous injection. Dale, Laidlaw, and Richards[22] showed clearly that histamine, when injected intravenously, produced widespread injury to capillaries throughout the body with resultant shock. With this evidence as a basis the traumatic toxemia concept of shock was brought forward by Quénu[23] and Cannon and Bayliss.[24] According to their hypothesis, a toxic substance was formed in traumatized tissues. This substance was absorbed into the blood stream and was carried to distant parts of the body, where it acted upon the capillaries to produce dilatation and increase of permeability. Attempts to demonstrate the presence of this hypothetical toxin in the circulating blood or in blood coming from an injured area, both by physiological[25] and by pharmacological[26] methods have been unsuccessful up to the present time. Underhill's[27] classical work on burns showed that the vessels in an injured area were more permeable in the direction of loss of plasma into the burned area but that the absorption from this area of even such diffusible substances as strychnine was prevented. The injection of blood coming from traumatized regions in Smith's[28] carefully controlled experiments showed that a rise in pressure generally resulted.

When the experiments which formed the basis of the toxemic theory were critically analyzed by Blalock,[29] Parsons, and Phemister,[30] and others, an alternative explanation could be found in the effect upon the circulation of the loss of blood or plasma into the traumatized area. Although it is undoubtedly correct that chemical substances from injured and inflamed areas do enter the blood stream and have their effect upon the tissues of the body, the character of the toxic reactions and the delay in their onset cast serious doubts upon their significance in the genesis of shock.

The chemical changes which take place in the body during the course of shock are brought about by the initiating factors, by the physiological reactions to the traumatic stimuli and by the failure of the circulation. Vomiting, diarrhea, sweating, kidney excretion, and the passage of plasma into an inflamed area result in the loss of specific substances from the body. The loss of these substances results in a diminution in their concentration in the blood stream and tissue spaces unless there has been an even greater loss of water. Under any circumstance, the total amount present in the body has been reduced In shock, associated with the loss of any of these substances, chemical examination of the blood will reveal the corresponding discrepancy.

The elevated blood sugar, which is found in shock may be regarded as one of the chemical responses of the body to trauma since it is produced by liberation of sugar from the liver through sympathetic stimulation In shock associated with adrenal or hepatic insufficiency, the blood

sugar is low. The increased potassium excretion in the urine after hemorrhage may also be thought of in terms of bodily reactions to correct the disturbance, since it is associated with the passage of fluid from the tissue cells into the blood stream.[31] It is recognized from the work of Zwemer and Pike[32] that sympathetic stimulation liberates potassium from the affected tissues.

With progressive circulatory failure certain chemical changes take place in consequence of the tissue anoxia. These changes, which are common to shock in spite of widely different initial causes have from time to time been signalized as of etiological significance in the genesis of shock. One of the first alterations to be noted was the acidosis and the consequent reduction in the carbon-dioxide content of the blood. Upon this deficit, Henderson[33] postulated his acapnea concept of shock. Attempts to produce shock by the injection of acid were unsuccessful and its treatment with alkali has not met with success. The acidosis present in the blood stream probably indicates only the accumulation of acids in the tissues which results from impaired oxygenation.

Zwemer and Scudder[34] have advanced the concept that "inadequate potassium regulation is also a factor which must be considered in any explanation of shock" It seems to be established that "hyperpotassemia" is present in shock, particularly when the condition has been brought about by widespread injury to tissues either through trauma or through anoxia. It is also probably true that an increase in the potassium of the blood is harmful to the heart and to other tissues. There is no evidence, however, that the hyperpotassemia itself produces an increase in the permeability of the capillaries. Since the loss of plasma through these injured vessels is the centrally important feature of shock, it does not appear that the increased potassium in the blood is etiologically significant in the genesis of shock.

The clinical picture of Addison's disease from lack of adrenal cortical hormone is similar to that of shock. Both patients and experimental animals with corticoadrenal insufficiency are particularly liable to develop shock under traumatic conditions. These subjects are dramatically improved by administration of cortical hormone. There is no convincing proof, however, that there is a lack of cortical hormone in shock or that therapy with this hormone is effective in the prevention or treatment of this condition.

With inadequate circulation there is an accumulation of chemical substances in the tissues which possess vasodilator properties. The exact nature of these products of tissue metabolism is unknown. They produce dilatation of the blood vessels in the ischemic area.[35] With re-establishment of the circulation they disappear. Their concentration is determined by the metabolic rate of the tissues and the duration of the circulatory deprivation.[36] With prolongation of the vascular insufficiency the cells are probably damaged with elaboration of products of their breakdown. These products may be related to histamine, or peptones Their action locally appears to be both to dilate the capillaries and to increase their permeability and to them may possibly be ascribed the

change in vascular permeability characteristic of shock. Our present knowledge of tissue chemistry is too inadequate to permit of more than speculation as to the nature of these substances. It seems safe to predict of future progress in our understanding of shock, as in our understanding of other processes, that "the last word will be said by chemistry."

Etiology: Any mechanism which brings about a discrepancy between the supply of oxygenated blood and the demand of the tissues for their metabolism is etiologically significant in the production of shock. Under this principle is considered all those factors which interfere mechanically with the distribution of blood to the tissues as well as the character of the blood and the properties of those tissues to which the blood is supplied.

The most frequent cause of shock in clinical cases is a mechanical interference with the circulation of blood to the tissues. This mechanical interference comes about in five ways: (*a*) Insufficient volume of blood, as after hemorrhage, dehydration or after major loss of plasma from burns or into an area of inflammation; (*b*) failure of the heart to deliver blood to the tissues as in cardiac tamponade or in cardiac failure; (*c*) mechanical impediment to the circulation of the blood, either on the arterial or on the venous side as in massive embolism; (*d*) reflex disturbances in the relationship between blood volume and vascular capacity as in the fall of blood pressure in spinal anesthesia, and (*e*) reflex vasoconstriction which obstructs the arterial flow in the arterioles, as in cold, fear, and pain.

(*a*) It is rare to encounter shock in clinical cases unless there has been serious loss of circulating plasma or blood volume. Blalock's[29] fundamental studies have indicated the significance of the local loss of blood and plasma into a traumatized or inflamed area. In consequence of this loss, there is a reduction of cardiac output. The blood pressure is maintained by the vasoconstriction but this protective device brings about further diminution in the volume flow of blood to the tissues. He demonstrated in unanesthetized dogs that shock could be produced by graded hemorrhages provided that the circulation was impaired for a sufficient length of time.

(*b*) Cardiac tamponade as Cannon[1] was the first to point out, provides an excellent example of shock produced by failure of the heart to deliver sufficient blood to the tissues The arterial blood pressure may be depressed to any desired level for various periods of time. He found that after the pressure had been lowered for several hours, it failed to rise even though the tamponade was relieved. The failure of the peripheral circulation in clinical cases of cardiac tamponade is well marked. So also with cardiac failure, the "forward failure" as Harrison[2] has defined it, there is insufficient supply of blood to the peripheral tissues with resultant shock.

(*c*) Mechanical impediment to the circulation of blood was used to produce shock in the experiments of Erlanger, Gesell, Gasser, and Elliott.[37] They found that shock could be caused by occlusion of the aorta below the diaphragm as well as compression of the vena cava in this location. Venous occlusion obviously impairs the return flow of blood to

the heart and in this way leads to a failure of cardiac output. On occlusion of the aorta, they found, as did Welch,[15] that congestion occurred in the splanchnic area. There appeared to result a segregation of blood in this region. Through peripheral stagnation, the available volume of blood was reduced.

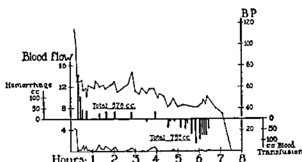


FIGURE 6 Effect of hemorrhage on blood pressure and blood flow of a normal unanesthetized dog In this, as in the following figure, solid line indicates blood pressure, interrupted line, blood flow through the hind paw. The amount and timing of hemorrhages is indicated by solid blocks at left; transfusions, shaded blocks below line at right Ordinates—blood flow and blood pressure. Abscissae—time in hours (Freeman Pennsylvania M. J)

(*d*) Any sudden disproportion between the blood volume and the capacity of the vascular bed brought about by expansion of the latter, will result in a failure of return of blood to the right heart in sufficient quantity to maintain the cardiac output. Under these circumstances, there will result a fall of blood pressure and its attendant phenomena Spinal anesthesia, according to Smith and his coworkers,[38] produces its deleterious effects upon the circulation by diminishing the venous return through paralysis of the muscles. The syncope which attends the erect posture in the absence of muscular activity and the carotid sinus reflex disturbances may be occasioned by similar mechanisms although the possibility of reflex cardiac inhibition of reflex dilatation of the veins under these circumstances must be borne in mind. Under any condition, the low blood pressure which these disturbances produce is not shock. Only when peripheral circulatory failure produces sufficient tissue anoxia to initiate progressive reduction of circulating blood volume, can the process of shock be said to have started.

(*e*) Vasoconstriction is a physiological mechanism which serves in a protective capacity in the face of a falling blood pressure. There is selectivity of the distribution of the reflex contraction of the arterioles with the preponderant effect in the skin and splanchnic area. In this way there is conservation of available blood flow for the vital organs, the heart and the brain, in which the sympathetic control is less powerful. Freeman[39] has shown that this vasoconstriction, which is a protective device for the crisis, may be the ultimate cause of shock in certain condi-

tions through the circulatory deprivation which it produces in the peripheral tissues. The dog, which has been sympathectomized by removal of both chains of paravertebral sympathetic ganglia, is more sensitive to loss of blood and will die sooner from a smaller hemorrhage than a normal dog. Yet this same animal will not go into shock, even though

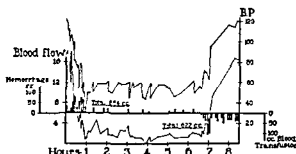


FIGURE 7 Effect of hemorrhage on blood pressure and blood flow of a dog which had recovered after bilateral thoracolumbar sympathetic ganglionectomy. At the conclusion of the experiment the dog jumped off the table and ran back to its cage (Freeman Pennsylvania M J)

its blood pressure be reduced to a lower level for a longer period than in the normal dog. Figures 6 and 7 illustrate the difference in reaction between the normal and the sympathectomized dog when the blood pressure was reduced by hemorrhage. In the absence of the sympathetic nervous system, the peripheral tissues are not deprived of blood to the same extent by the low blood pressure as under the influence of vasoconstriction It is possible that certain traumatic factors, such as pain, cold, and fear, exert their influence in the production of shock through vasoconstriction.

The character of the blood determines its usefulness in the function of supplying oxygen to the tissues. In this manner, any reduction in the oxygen-carrying capacity of the arterial blood, such as in anemia, means that a greater volume flow of blood is necessary to meet the oxygen requirements of the tissues. Similarly, if the oxygen content is reduced through inadequate oxygenation of the blood in its passage through the lungs, the volume of circulation will need to be greater. Since asphyxia is capable of reflex stimulation of the vasoconstrictor mechanism, the possibility of double damage to the nutrition of the body cells is present. Bayliss[40] has called attention to the importance of this consideration in his statement "At the risk of tiresome iteration, I would again emphasize the importance of *adequate oxygen supply* to the tissues."

Another consideration which will affect the oxygenation of the cells in relation to a given blood flow is the metabolism of the tissues. In the first place the cells may be unable to use the oxygen supplied to them by the blood. Under these circumstances, according to Peters and Van Slyke[41] a "histotoxic anoxia" will develop. Our knowledge of the funda-

mental mechanisms which determine this disturbance is too meager for discussion. An increased metabolic rate, on the other hand, is a well recognized condition. Fever determines an increase in the oxygen requirements of the cells to a marked extent. In this way, any reduction in the available circulation will make itself felt more rapidly and with greater consequence. The terminal shock of acute infections and the phenomena of a thyroid crisis are probably associated with a circulatory discrepancy engendered quite as much by extraordinary metabolic rate of the tissues as by reduction of the volume flow of blood to these cells.

Prognosis: The prognosis, in cases of shock, is determined by the severity of the circulatory deprivation and the time during which this inadequate supply of blood to the tissues has been present. This fact is well illustrated by the rapid improvement which the patient shows in case of hemorrhage when the bleeding is stopped and a transfusion of blood is given. After shock has progressed to the stage of hemoconcentration with segregation of the blood in the peripheral and splanchnic capillaries no therapy can interrupt the vicious circle. The "time factor" in shock has been forcibly stressed by Cannon.[1]

Treatment: Since shock is the progressive loss of circulating blood volume due to the tissue anoxia which results from impaired circulation it is imperative to interrupt the process at the earliest possible moment before serious tissue damage is produced. In order to check the course of shock an adequate supply of oxygenated blood, sufficient to meet the tissue requirements, must be achieved. The etiological factors have been enumerated above and the treatment of shock will be described under the same categories

(*a*) Since shock is usually produced by insufficient volume of blood or plasma, replacement of this loss is the most effective therapeutic agent. In case shock has been brought on by hemorrhage, transfusion of blood is manifestly the appropriate treatment. The lost blood should be replaced at the earliest possible moment after the bleeding has stopped. There are two circumstances which may prevent the carrying out of this objective: Lack of suitable blood and in a condition when further bleeding is to be feared.

In default of appropriately matched blood, there are various blood substitutes which may be used. Fresh plasma is probably the best of these substances.[42] It will provide the necessary volume with a colloid osmotic pressure which will hold it in the vascular system. It lacks the oxygen carrying capacity but the hemoglobin content of the blood can be reduced to extremely low levels without great harm provided that the volume be maintained. The possibility of the storage of plasma in the dried or "lyophile" form offers opportunities for wider usefulness.[43]

Gum acacia was suggested as a blood substitute by Bayliss.[40] It has approximately the same viscosity in a six per cent solution that plasma has and has the advantage over solutions of electrolytes that it exerts a colloid osmotic pressure. It is held within the blood stream for long periods of time. The drawback to the use of acacia is the difficulty of its elimination Traces have been found in the circulation as long as

three years after its administration.[14] Its deposition in the liver has been noted. In an emergency, it is valuable. Five hundred cubic centimeters of a six per cent solution are given intravenously with immediate benefit in restoration of blood volume.

The circulatory volume can be temporarily sustained by the intravenous administration of physiological saline or five per cent glucose. This fluid is held in the circulation for as long as an hour and should be used in the treatment of hemorrhage until blood or some better substitute becomes available. In cases of hemorrhage which are not serious, the body will be able to make its own readjustment provided that sufficient water and salt can be called on.

In the treatment of hemorrhage, fluids administered by the gastrointestinal track seem to be better handled than fluids administered parenterally, as Robertson and Bock[3] showed. In many cases vomiting or gastrointestinal hemorrhage will prevent the intake of fluids by mouth. In such cases, water or salt solution can be given by rectum.

The fear is occasionally expressed of giving fluids intravenously because of the danger of "overloading" the circulation. For this reason their administration by hypodermoclysis has been advocated. The danger is probably overestimated as the quantitative studies of Altschule and Gilligan[15] have shown. The normal circulation can tolerate the intravenous administration of isotonic fluid at a rate of 10 to 20 cc. per minute without any rise in venous pressure. In cases of congestive heart failure with increased venous pressure, fluids can be given slowly at 2 to 4 cc. per minute without increasing the pressure since the salt solution leaves the circulation at approximately the same rate. The disappearance of fluid from the subcutaneous spaces when injected hypodermically is probably more rapid than the slow rate at which it is given intravenously by the drip method now employed. An additional reason for giving it into the vein is the freedom from discomfort.

In case that further bleeding is to be feared, the treatment of hemorrhage offers one of the most difficult problems in judgment which the practice of medicine affords The ideal to be striven for if surgical intervention is not feasible, is the maintenance of life until the physiological and chemical forces of the body should have controlled the bleeding. In the final analysis, the patient should be allowed to go to the edge of shock without entering the vicious circle of progressive loss of circulating blood volume through tissue anoxia. With this concept in mind, upon what considerations can the physician depend to guide him in his treatment? Here, as in few other conditions, the most careful watch should be kept for signs of oncoming shock One of the earliest evidences that the body is under strain is restlessness. In experiments on dogs under local anesthesia,[18] it was repeatedly observed that restlessness was a premonitory sign of shock. This change in the behavior seemed to occur at a critical period when the additional loss of a small amount of blood would precipitate the downward course.

A rising pulse rate and a falling blood pressure are unmistakable signs of shock. They may not give such specific indications of the correct

time to take measures to prevent shock as the behavior of the peripheral circulation. As long as there appears to be an adequate supply of blood to the periphery as indicated by a pulse of palpable volume and warm extremities, shock, in the presence of hemorrhage, need not be feared. The appearance of the lips, the ears, the nose, and the circumoral region is of diagnostic significance. When vasoconstriction produces an "ashen" appearance and the face and hands are cold and sweaty, the process has reached a crisis which demands intervention. Frequent determinations of the concentration of the blood should be made. As long as dilution is proceeding after hemorrhage, the process is one of restoration of blood volume from the extravascular fluid reservoirs. When the process of dilution is checked, or if concentration occurs, the process of shock has then already started.

The treatment which seems to offer the best results in maintaining life in the face of continued bleeding is the continuous "drip" transfusion suggested by Marriott.[46] During the course of this treatment, careful observation of the "general condition" of the patient must be made.

The administration of stimulating drugs in shock from hemorrhage is not only useless but probably harmful except as a last resort if a fatal outcome seems imminent.

In shock brought on by dehydration, treatment demands first of all the replacement of the fluid lost. In this restoration, it is of importance to appreciate the fact that various salts have been lost in addition to water when dehydration has been caused by excessive vomiting, diarrhea, drainage or urinary secretion. It is essential also to realize that through insensible perspiration there has been going on a loss of water without salt. It is hard to say which of these losses it is the more imperative to replace. From the standpoint of mechanical volume, the administration of water is the chief factor. The electrolyte balance, however, must be maintained in order to permit proper functioning of renal and other tissues. Fortunately, in the form of 0.9 per cent sodium chloride solution (physiological saline), both salt and water are available. Provided that the kidneys are able to function, the body can regulate the excretion of either anions or cations so as to achieve the necessary balance.[47] However, a supply of water is essential for adequate renal function. Five per cent glucose in distilled water is more readily excreted than physiological saline. The total quantity of fluid necessary to correct a state of dehydration is large. Maddock and Coller[48] have determined the fluid needs in surgical patients and have found that it was necessary to give as much as six per cent of the body weight, in addition to the daily requirements to correct the state of dehydration present in patients at the time of admission. Coller and his associates[49] have described the technic for replacement of the salt lost by vomiting, diarrhea, and profuse drainage.

Even though the external loss has been one of water and salts alone, when dehydration reaches a critical stage of impending shock, recovery will not always follow replacement of the lost materials. Keith[50] in his experiments upon dehydration produced by the intravenous injection of sucrose, found that if the state of dehydration were not allowed to

persist for long, recovery by replacement was effected. However, if he waited too long before replacing the fluid lost, recovery could not be brought about.[51] The clinical experience of pediatricians in dealing with dehydration associated with diarrhea and vomiting showed that in the serious cases, the fluid administered was not retained in the circulation but was found at necropsy in the tissue spaces and in the serous cavities. It seems probable that the decreased circulation brought about through dehydration produces sufficient tissue anoxia to impair the permeability of the vessels so that a loss of plasma ensues with consequent reduction of total amount of plasma protein in the circulation. Even though the concentration of plasma proteins is elevated during the course of dehydration, the absolute amount is decreased. Support for this concept is furnished by the consistency with which low values for the serum protein concentration are found after recovery from dehydration has been effected. This reduction in the serum protein concentration facilitates the development of edema, particularly in the presence of excessive administration of salts. Thompson, Ravdin and Frank[52] have emphasized the significance of low blood proteins in faulty postoperative wound healing. Hypoproteinemia, as Barden, Ravdin, and Frazier[53] first showed, disturbs the function of the gastrointestinal tract.

The following case illustrates the treatment by transfusion of a patient suffering from shock as a result of dehydration:

CASE 1: F. P. DeV., University Hospital, No. 37,422 The patient was a white man of thirty-six years, who had sustained four previous abdominal operations for regional ileitis He was first admitted to the hospital forty-eight hours after the onset of acute intestinal obstruction There was distention and fecal vomiting. He was *in extremis* with a systolic pressure of 60 and a pulse rate of 134. His extremities were cold and cyanotic There was marked tetany with positive Chevostek sign. The blood studies showed a red cell count of 4.76 million and a hemoglobin of ninety per cent The white blood cells numbered 8300 The chlorides were eighty-three milli-equivalents per liter and the carbon dioxide capacity fifty-six volumes per cent Immediate intravenous treatment was started. In the succeeding eighteen hours he received 1150 cc. of blood and 4130 cc. of five per cent dextrose in physiological salt solution The stomach was decompressed by suction through a Miller-Abbott tube At the end of eighteen hours, the clinical picture had changed dramatically. The pulse was ninety-two with full volume and the extremities warm and dry Blood studies repeated the following day showed that the chlorides had come up to normal, 102.8 milli-equivalents and the carbon dioxide to sixty-two volumes per cent The serum proteins were 4 8 grams per 100 cc in spite of the fact that he had received 1925 cc of blood in multiple transfusions. The hemoglobin did not exceed ninety-six per cent although the red blood count on the second day went up to 5 54 million This patient illustrates the necessity of administering fluid with colloid osmotic pressure which will stay in the circulation The low serum protein concentration, even after giving so much blood, indicated the severity of total circulating protein deficit that must have existed at the time of admission.

Through exudation of serum from a burned area or by the loss of plasma into an area of inflammation, the circulating plasma volume is frequently reduced. This loss is always a serious one since, in addition to

the decrease in blood volume, there is hemoconcentration with increase in the blood viscosity which leads to further impairment of circulation. Replacement of the lost fluid by the intravenous injection of fluids without colloid osmotic pressure will not restore the plasma volume. The vessels are unable to retain the fluid injected and the concentration of the blood is not relieved. Treatment by transfusion is effective through increasing the blood volume but here, as in few other conditions, the optimum therapy is the administration of plasma.[42] Not only is the volume of the circulation increased but the condition of hemoconcentration is relieved. In shock from acute pancreatitis, or from strangulation of the intestine, the loss of plasma into the peritoneal cavity is large. The fluid has a protein content which ranges from two to four per cent. Treatment demands the replacement of the protein, as the following case illustrates:

Case 2 D S, University Hospital, No. 38,182. The patient was a sixteen-year-old girl with ulcerative colitis of three months' duration She was acutely ill on admission, quite pale and "washed out" The abdomen was doughy and tender along the course of the colon The red blood count was 4 1 million and the hemoglobin seventy-four per cent and the white blood count 14,000 By the following day the hemoglobin had fallen to sixty-eight per cent in spite of a transfusion of 500 cc. of blood. A note was made that the "patient shows marked hyperactivity of the sympathetic nervous system chiefly characterized by peripheral vasoconstriction on afferent stimulation." The diarrhea continued with between seven and eleven loose stools each day. These bowel movements contained blood and pus In the next three days, although she received four transfusions in which a total of 1400 cc. of blood were given, the red blood count dropped to 3 58 million and the hemoglobin to sixty-two per cent. An ileostomy was then performed Upon opening the peritoneal cavity, a large amount of free fluid was encountered This fluid on analysis proved to have a protein content of 3 2 grams per 100 cc The bowel wall was inflamed but was not covered with fibrin Culture of the fluid yielded no growth of bacteria After operation, she received three blood transfusions and the hemoglobin came up to ninety-six per cent

This case is presented to illustrate the large amount of blood which is lost from the inflamed gastrointestinal tract. Further loss of plasma into the peritoneal cavity, even without frank peritonitis, brings about additional reduction of circulating blood volume. Treatment by the injection of water and salts alone will not replace the osmotically active substance which has been lost with the plasma

(*b*) When the peripheral circulatory failure has been brought about by failure of the heart to deliver an adequate supply of blood to the tissues, therapy must be directed toward improving the cardiac function.

The process of shock will occasionally be encountered in a patient who has a damaged heart and the question will come up as to whether or not the circulation will stand the administration of blood, plasma or other intravenous fluid. In answer to this question, it is only necessary to emphasize the fact that the myocardium needs an adequate supply of blood for its proper functioning. Correction of a low blood pressure and of hemoconcentration will probably result in an improvement of

cardiac function. Again, cardiac hyperactivity is one of the most fundamental physiological reactions to shock. When the crisis is passed the stimulation subsides. From these considerations, the conclusion is reached that shock should be treated in the cardiac patient from the standpoint of the heart if that organ is the primary factor. Otherwise, therapy should be directed toward relieving the burden which alteration in the state of the circulating blood volume places upon the heart.

(*c*) Where shock is brought about through gross obstruction of the arterial or venous circulation, best results will naturally follow removal of the obstruction. In only occasional instances will this solution be possible. The development of collateral circulation is effective provided that time is allowed, but with sudden obstruction, as by an embolus, a condition develops which frequently goes on to shock and death before the collaterals can develop. The original obstruction may not alone be sufficient to produce death but there develops from that block an extensive thrombosis, which precludes recovery. If the arborization thrombosis can be prevented, time is allowed for the development of collateral circulation.

Heparin[54] has recently been developed for intravenous use in patients It will prevent the extension of the thrombotic process. In addition, the development of further emboli is prevented. The solution is supplied by the Connaught Laboratories of Toronto. It should be given by the continuous intravenous drip. The contents of two vials, or 20,000 units daily will increase the clotting time from seven to somewhere between thirteen and eighteen minutes. In a series of six cases of sublethal pulmonary embolism,[55] there were no deaths and no recurrence of the embolic phenomena. In peripheral arterial embolism, the prospect of successful surgical removal is increased by the administration of heparin since thrombosis at the suture line is inhibited. Even in case that the removal cannot be accomplished, arborization thrombosis is prevented so that there is time for the reestablishment of the circulation through collaterals Mesenteric thrombosis has also been treated with consistent success by the use of this material. Heparin is thus of use in the treatment of shock when there exists a mechanical obstruction to the flow of blood from a clot in the vessels.

(*d*) The only occasion when stimulants are effective in the treatment of shock is when the process is being initiated through the fall of blood pressure which results from reflex inhibition of cardiovascular or muscle tone. Even in these circumstances, the preventive treatment by administration of the drug before the fall is more effective than after the fall in blood pressure has occurred Henderson[56] and his coworkers have shown that a decrease in muscle tone may occur in patients after operation and that this drop is prevented by the use of strychnine. A current of air played upon the skin is also effective in restoration of tone. He and his associates[57] found that the weakness experienced by an individual in a humid environment without movement of air currents was associated with low muscle tone and that this condition could be corrected by keeping the air in motion. It is possible that the beneficial

effect of adequate ventilation is due to the increase in tone producéd in this way.

The time-honored use of the recumbent posture is the most effective method of improving the circulation when the depression results from pooling of blood in the venous reservoirs. The "head-down" position favors the return of blood to the right heart. After spinal anesthesia has been induced, a serious fall in blood pressure and syncope will be produced if the body is raised into the vertical position. In the prevention of the fall in blood pressure under spinal anesthesia, the use of vasoconstrictor drugs seems to have a logical place which has been confirmed by experience. Ephedrine in doses of 25 mg. a half hour before injection of the anesthetic and, in case that the pressure is not elevated, immediately before the solution is injected into the subarachnoid space, is usually effective in preventing a serious fall in blood pressure.[58] After the spinal anesthesia has been administered, this drug is not so effective in restoring a pressure which has fallen. The use of adrenalin, benzedrine, and neosynephrine has been found valuable under these circumstances.

Investigations by Kunkel, Stead, and Weiss[59] have shown that in paredrinol, there is afforded a substance which increases the venous tone without at the same time producing marked vasoconstriction in the arterioles. It was effective in preventing syncope induced by the administration of nitrites when the subject was tilted in the horizontal position. Its use in the treatment of clinical shock on the medical wards, especially if there was a decrease in blood volume, was not beneficial.

There are various other methods of increasing muscle tone in order to raise the venous pressure. An interesting one was recently suggested by Ornstein, Licht, and Herman.[60] They stimulated the muscles of the abdomen and buttocks with faradic current and observed an increase in venous pressure. Its successful use in the treatment of traumatic shock was reported in one case. This method would appear to be too cumbersome for general use. A simpler method and one which was used for many years is centripetal massage of the extremities. It seems likely that blood which is stagnant in the peripheral portions of the body may be brought back into the circulation by this method. Provided that the blood flow to the tissues of the body is not too long impaired the process of shock will not be initiated.

(*e*) Vasoconstriction is one of the protective mechanisms of the body which is brought into play by trauma or the expectation of injury. It is useful in the emergency, to mobilize the resources of the organism. The physiological attributes of vasoconstriction have been discussed in the section of this chapter devoted to the consideration of the physiology of shock. Even though constriction of the vessels of the peripheral portions of the body is beneficial in the crisis, serious consequences are produced if that constriction is too protracted. The arterioles are contracted, and, although the pressure proximal to the narrowing may be raised, blood flow is reduced. The nutrient supply to the tissues may be so far cut down that actual necrosis may ensue. Such an event is to be seen

in the gangrene of the finger tips brought about through frequent spasms of the digital arterioles in Raynaud's disease.

Generalized vasoconstriction, such as that which results from the intravenous administration of adrenalin, may be so intense and produce such a deficiency in the blood supply to the tissues that shock can be produced. In the unanesthetized dog, as shown in Fig. 8, if the dosage

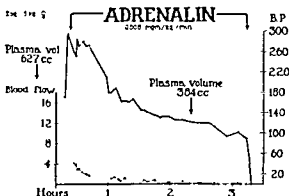


FIGURE 8 Effect of intravenous injection of adrenalin (0 008 mg per kg per minute) on blood pressure, plasma volume, and blood flow through the hind paw of an unanesthetized dog Solid line—blood pressure Interrupted line—blood flow Arrows indicate plasma volume measured by the blue dye T-1824, at times indicated. Ordinates—blood flow, left, and blood pressure, right. Abscissae—time in hours. The blood flow is recorded in cubic centimeters per 100 cc tissue volume per minute (Freeman: Pennsylvania M J)

of adrenalin is increased to produce a severe reduction in peripheral blood flow, a marked decrease in blood volume with hemoconcentration results.[39] On microscopic examination of the tissues, there is found congestion in the minute vessels of the splanchnic area.

The vasoconstriction hypothesis is useful in that it provides an explanation of the fact, long recognized, that pain, fear, and cold are capable of producing shock or of aggravating the condition if present. The fundamental physiological reaction of the body to these stimuli is vasoconstriction. It is a purposeful response. If the emergency is too severe or protracted, the very mechanism by which the body strives to survive, may bring about its ultimate dissolution. Clinical cases of shock precipitated by fear have been encountered and a surgeon of such wide experience as J. M. T. Finney[61] has emphasized the importance of the emotional attitude of the patient prior to operation. The following case history is given to illustrate the physiological reaction produced by apprehension in a patient:

CASE 3 G H., Massachusetts General Hospital, No 349,187 The patient was a forty-three year old white female who was operated upon for uterine bleeding A total hysterectomy was performed under ether and local anesthesia Before operation, the patient had been examined by four different physicians and they had all commented upon the emotional instability which she manifested. During the course of her operation, although the blood pressure was well maintained, the pulse rate was 112 beats per minute Special care was

taken to prevent the loss of blood and after operation she was given 1800 cc. of fluid intravenously. That night her condition was excellent, pulse ninety-two, blood pressure 100/85 However, she was sweating and uncommunicative. The following morning she was in shock with a pulse of 150 and a blood pressure of 94/86 Her skin was cold and clammy. She was vomiting coffee-ground material. Examination failed to reveal intraperitoneal hemorrhage or other cause for her condition It was felt that she was suffering from shock brought about through fear She was transferred into a separate room and studies of the volume flow of blood through her hand were made. At the start, the flow was very low. During the course of the examination which lasted for one and one-half hours, no attention was paid to her condition No treatment was instituted. As the studies were calmly pursued a steady increase in the circulation through her hand was observed. At the end of the time, the flow was normal. She opened her eyes and the skin of her face became flushed. The extremities were warm and the pulse of good quality. She proceeded to a normal convalescence This case is presented to illustrate the profound physiological effects which can be brought about through emotional distress

One word of caution is needed in the interpretation of so-called "psychic shock" The diagnosis can be suspected but not until adequate organic cause for the condition is excluded either by recovery or by careful necropsy can the nature of the etiological factor be established.

In the treatment of shock produced or aggravated by vasoconstriction it is necessary to inhibit the action of the sympathetic nervous system. To produce this inhibition, either the exciting cause can be elimnated or the patient prevented from reacting to the stimulus. It might be considered advisable, at first glance, to block the sympathetics on the efferent side since it was shown that the sympathectomized animal will not go into shock. However, even though this animal will not go into shock it will succumb from hemorrhage more readily than the normal animal, since it cannot maintain, through constriction of the vessels, a blood pressure sufficient to supply blood to the brain. If the patient were deprived of his sympathetic nervous system, he might not be able to respond to the crisis at all. Although shock would not be produced the patient would die. From this consideration, it would seem more logical to inhibit the sympathetic system by removing the stimuli which call it into activity. The treatment of shock should be based on the causes of vasoconstriction as enumerated in Fig. 9.

When pain, fear, and cold are producing vasoconstriction, the obviously correct therapy is morphine, reassurance and warmth. These remedies are the classical ones in the treatment of shock and assume new significance in view of the vasoconstrictor hypothesis. For other factors which stimulate the sympathetic nervous system, such as dehydration and hemorrhage, the treatment has been detailed above and again is well established

When the patient is gripped by fear, it may not be possible to reason with him or reassure him. It is in this instance that the administration of alcohol intravenously as Frazier[62] suggested, has a definite place. It can be given by continuous venoclysis, 30 cc. (1 ounce) to 500 cubic centimeters (1 pint) of five per cent glucose or salt solution. The patient is kept pleasantly inebriated and is indifferent to his surroundings. At the

same time the alcohol produced peripheral vasodilatation and offers a supply of readily combustible carbohydrate.

The therapy of shock, aggravated by deficiency in oxygen-carrying capacity of the blood, is clearly the restoration of the hemoglobin content by transfusion. In case that the oxygen content is reduced by asphyxia, the administration of oxygen by inhalation is valuable. In some clinics,

SHOCK

CAUSE	TREATMENT
Hemorrhage	Transfusion
Dehydration	Fluids
Pain	Morphine
Cold	Warmth
Fear	Reassurance
Asphyxia	Oxygen
Exhaustion	Rest

FIGURE 9 The treatment of shock (Freeman· Pennsylvania M J.)

the routine treatment of shock embodies the use of oxygen at high tension. When the oxygen saturation of the arterial blood is already normal, the use of oxygen does not seem to rest on a rational basis. Its use in shock from asphyxia is imperative.

When there is reduced peripheral blood flow combined with an increased rate of utilization of oxygen by the tissues as in fever or in hyperthyroid states, a condition of tissue anoxia is more readily brought about. In addition to therapy directed toward increasing the supply of blood to the tissues, efforts should be directed toward reducing the tissue needs by lowering the metabolic demands. The temperature must be kept from reaching excessive heights. To this end, ice bags, exposure of the body to cool air, and ice packs may be used. Frequently, especially in states associated with extreme vasoconstriction, the extremities will be cold while the body is raging with heat. Under such circumstances ice water enemas may be employed.

In shock associated with toxemia from infections, specific therapy with antitoxins is useful where possible. Again, surgical drainage of infected collections frequently bring gratifying results as far as the general condition is concerned

CONCLUSIONS

Shock is the clinical condition characterized by progressive reduction of circulating blood volume brought about by tissue anoxia which results from inadequate circulation.

The clinical picture depends upon the physiological reactions to the traumatic stimuli and upon the bodily responses to inadequate circulation.

The pathological findings are those of stagnation of blood in the peripheral and splanchnic areas and of tissue damage from inadequate circulation.

The most significant physiological alterations are those of the cardiovascular system and they give evidence of widespread sympathetic stimulation.

The chemical changes are chiefly dependent upon the circulatory deficiency. No chemical substance capable of producing shock has yet been consistently demonstrated in the circulating blood, in sufficient quantity to cause shock.

Any mechanism which brings about a discrepancy between the supply of oxygenated blood and the demand of the tissues for their metabolism is etiologically significant in the production of shock.

Duration of circulatory impairment determines the prognosis.

Treatment should be directed toward assuring an adequate supply of oxygenated blood to the tissues. Only when this aim has been achieved can the therapy of shock be termed satisfactory.

REFERENCES

1 Cannon, W B "Traumatic Shock," pp 10, 63, 102, D Appleton & Co, New York, 1923.
2. Harrison, T R · "Failure of the Circulation," p 17, 2nd Ed, Williams & Wilkins Co, Baltimore, 1939
3 Robertson, O H, and Bock, A V. Spec Res Ser med Res Comm, London 25 213, 1918
4 Keith, N M Spec Res Ser med Res Comm., London 26:36, 1919.
5 Cannon, W B, Fraser, J and Hooper, A. N Spec Res Ser. med. Res Comm, London 25:72, 1918
6 Moon, V H. Ann Int Med 13 451, 1939
7 Aub, J C: Am J Physiol 54 388, 1920
8 Aub, J C, and Cunningham, T. D Am J. Physiol 54·408, 1920.
9 Blalock, A, and Bradburn, H Arch Surg 20 26, 1930
10 Freeman, N E, Shaw, J L, and Snyder, J C.: J. Clin Invest. 15:651, 1936.
11 Erlanger, J, Gesell, R., and Gasser, H S: Am J. Physiol 49·90, 1919
12 Gesell, R. Am J Physiol 47 468, 1919
13 Blalock, A, and Levy, S E · Am. J Physiol 118 734, 1937.
14 Cannon, W B · Am J Psychol 25:256, 1914
15. Welch, W H. *Embolism* in "A System of Medicine," 2nd Ed, Vol. 6, p 762 Sir Clifford Allbutt and H D Rolleston, The Macmillan Co, New York, 1909
16 Landis, E M Am. J Physiol. 83 528, 1928
17 Gasser, H S, Erlanger, J, and Meek, W J: Am J. Physiol 50:31, 1919
18 Freeman, N E, Shaffer, S A, Schecter, A E, and Holling, H. E: J. Clin Invest 17·359 (May) 1938
19 Johnson, G S, and Blalock, A Arch Surg 23:855, 1931.
20 Freeman, N. E, Morison, R S, and MacKay Sawyer, M. E.: Am J. Physiol 104·628, 1933
21. McCulloch, H: Am. J Dis. Child. 20:486, 1920
22. Dale, H H., Laidlaw, P. P, and Richards, A N.· Spec Res. Ser med Res. Comm., London 26:8, 1919
23 Quénu, E.: Rev chir. 56 204, 1918

24 Cannon, W B, and Bayliss, W. M. Spec. Res Ser med Res Comm, London 26·19, 1919
24 Cannon, W. B, and Bayliss, W M. Spec Res Ser. med Res Comm. London 26·19, 1919
25. O'Shaughnessy, L., and Slome, D. Brit J. Surg 22 589, 1935
26. Dragstedt, C. A, and Mead, F. B · J A.M A 108 95, 1937
27. Underhill, F. P, Kapsinow, R, and Fish, M E Am J Physiol 95 315, 1930
28. Smith, M. I. J. Pharmacol & Exp Therap 32.465, 1928
29. Blalock, A.· Surg, Gynec & Obst. 58 551, 1934
30 Parsons, E, and Phemister, D B. Surg, Gynec. & Obst 51 196, 1930
31. Stewart, J D, and Rourke, G M · J Clin Invest 15 697, 1936
32. Zwemer, R L., and Pike, F. H Ann N Y Acad Sc 37 257, 1938
33 Henderson, Y: Am J Physiol 21·126, 1908
31 Zwemer, R L., and Scudder, J Surgery 4 510, 1938
35. Lewis, T, and Grant, R Heart 12 73, 1925
36 Freeman, N E: Am. J Physiol 113 384, 1935
37. Erlanger, J, Gesell, R, Gasser, H. S, and Elliott, B L. J A M A 69 2089, 1917
38 Smith, H. W, Rovenstine, E A., Goldring, W, Chasis, H, and Ranges, H. A J. Clin. Invest 18·319, 1939.
39. Freeman, N E.· Pennsylvania M J 42 1449 (Sept) 1939
40 Bayliss, W. M.: "Intravenous Injection in Wound Shock," p 69, Longmans, Green and Co, London, 1918
41 Peters, J P, and VanSlyke, D. D "Quantitative Clinical Chemistry Interpretations," p. 579, Williams and Wilkins Co, Baltimore, 1931.
42. McClure, R. D · J A.M.A 113 1808, 1939
43 Bond, D D., and Wright, D G. Ann Surg 107 500, 1938
44 Keith, N M, Power, M H, and Wakefield, E G Proc Staff Meet., Mayo Clin. 10 38, 1935
45. Altschule, M D, and Gilligan, D R J Clin. Invest 17 401, 1938
46 Marriott, H. L., and Kekwick, A Lancet 1.977, 1935
47 Gamble, J. L, and Ross, S. G J Clin. Invest 1.403, 1925
48 Maddock, W. G, and Coller, F A J A M A 108 1, 1937
49 Coller, F. A, Bartlett, R M, Bingham, D L. C, Maddock, W G, and Pedersen, S Ann Surg 108·769, 1938
50 Keith, N. M · Am J. Physiol 68 80, 1924
51 Keith, N. M. Personal communication
52 Thompson, W. D, Ravdin, I S, and Frank, I L.· Arch Surg 36·500, 1938.
53. Barden, R P, Ravdin, I S, and Frazier, W D Am J Roentgenol 38 196, 1937
54 Murray, G D W, and Best, C H J A M A 111·1134, 1938
55 Murray, G D W, and Best, C H Ann Surg 108 163, 1938
56. Henderson, Y, Oughterson, A W, Greenberg, L A, and Searle, C. P · Am J. Physiol 114 261, 1936
57 Henderson, Y, Oughterson, A W, Greenberg, L A, and Searle, C P.. Am J. Physiol 114 269, 1936.
58 Ferguson, L K, and North, J P. Surg, Gynec, & Obst. 54·621, 1932
59 Kunkel, P., Stead, E A, Jr, and Weiss, S · J. Clin Invest 18 679, 1939.
60 Ornstein, G C, Licht, S, and Herman, M · Quart Bull. Sea View Hosp 4 333, 1939
61. Finney, J M. T. Ann Surg 100 734, 1934
62. Frazier, C. H. J A M A 105 1731, 1935.

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Rehabilitation of the Patient with Cardiovascular Disease

The increasing significance of public health and the economic and community implications of cardiovascular disease have received increasing recognition in recent years. The magnitude of the problem of cardiovascular disease justifies such recognition. Each year in the United States, at least 653,000 man-years of production are lost to America's productive capacity because of heart disease disabilities. This loss in man-years is equivalent to $3,246,030,000 (1957) alone in earnings by those suffering from disabilities of heart disease, and $444,693,000 in federal income tax revenues on these earnings in the same year. These figures are exclusive of unemployment, sickness and disability, hospitalization and medical, as well as public assistance, costs. Nor do these include the similar costs and losses resulting from the estimated 1,800,000 cases of hemiplegia resulting from cerebrovascular accidents. Industrial absenteeism in the United States as the result of cardiovascular disease and its complications is preceded in incidence only by that caused by respiratory diseases. In addition, patients disabled by heart disease represent almost 50 per cent of all the nontraumatic cases seen on most rehabilitation services.

CARDIAC DISEASES

The most important factor in the successful rehabilitation of the patient with cardiac disease is motivation. Even though his physical or functional capacity may be limited, the patient with cardiac disease can be rehabilitated to live the most normal life possible within the limits imposed by his disease. This can be done, however, only if the patient is motivated. His attitude and that of his family are greatly influenced by the physicians with whom he has contact. Both the personal family physician and the specialist should take time to discuss thoroughly with the patient and the family such problems as physical activity, emotional and environmental stress, the nature of the disease, the need for specific therapies and the prognosis for survival and return to a normal life. Throughout these discussions, the physician should emphasize the positive factors and stress the likelihood that the patient can continue to lead a satisfactory life with limitations.

As in other conditions, the medical evaluation of the patient with cardiac disease is the foundation of rehabilitation. It should include a careful, accurate, and thorough history, as well as a complete physical examination

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and appropriate technical and laboratory studies. In this examination the physician should include an assessment of the patient's functional capacity. This may be simple if the patient can perform the normal activities of life without distress, or it may be difficult if he is unable to do so or if he is recovering from a recent myocardial infarction or an attack of rheumatic fever. Under the latter circumstances, tests of tolerance are seldom carried out, and the patient is usually advised regarding activity on the basis of what the physician considers safe and proper rather than on the patient's functional status at that time.

Functional capacity can usually be adequately estimated by a detailed history of the patient's response to physical activity, but when the physician is not satisfied with the information he obtains by history, he should observe the patient during physical activity to determine functional capacity. Walking on a level surface, climbing stairs, or Master's two-step or double two-step tests are methods which the physician can use to determine the patient's tolerance for sustained activity and for peak loads of activity. Various tests have been devised to aid the physician in estimating the functional capacity of the cardiac patient, but under ordinary circumstances it is not practical to utilize these tests in the average patient. It is also important to realize that these tests may not aid the physician in assessing the capacity of the patient to perform a specific job

After the physician has estimated the functional capacity of the patient, he must then estimate the physical and emotional stresses of the patient's daily life, including job, travel, home, and the like, to determine if the patient can return to his usual way of life. Considerable information is now available on the energy requirements of a variety of activities, jobs in industry, the physiologic stresses imposed by a hot and humid environment, and the stresses imposed by the patient's emotional reactions. When the physician knows specifically which of these stresses the patient is likely to encounter in his daily life, he can appropriately advise his patient about his activities. This advice can be given with greater assurance if the physician appreciates the fact that the majority of jobs in American industry today do not require more than three or four times the basal energy expenditure (often much less energy is expended on the job than in off-the-job activities) It is also important for the doctor to realize that cardiac and noncardiac workers expend essentially the same amount of energy in performing a given task which is within their physical capacity and with which they are equally familiar.

In advising his patient about work and physical activity, the physician should be aware of the fact that static and dynamic work impose different physiologic stresses on the cardiovascular system. For comparable amounts of physical work accomplished, static work imposes a far greater stress than does dynamic work. The pulse rate will rise much more quickly, and sudden decreases and increases in cardiac filling and in peripheral resistance are likely to occur, which may cause vascular rupture or acute arrhythmias or which may result in the sudden development of heart failure in a patient with an impaired cardiovascular system

The relative importance of nonoccupational versus occupational stresses

should also be kept in mind Coughing or raising intra-abdominal pressures to hasten the expulsion of urine, feces, or flatus imposes burdens which are analogous to those caused by lifting heavy objects. Less severe, but more sustained, circulatory stress may be imposed by sexual intercourse. Work in the home or garden, dancing, or participation in sports causes stresses equivalent to those of occupations which involve climbing stairs or ladders, hammering, or repeatedly lifting objects weighing up to 20 pounds. Although these activities may cause no alarming symptoms, they may help to set the stage for an attack of nocturnal dyspnea or for gradually increasing edema and breathlessness. Traveling to and from work may also induce considerable physical, as well as emotional, stress. This is becoming increasingly true with traffic congestion on the roadways and greater congestion in metropolitan and industrial areas.

The combination of high environmental temperature and humidity is another stress, often nonoccupational, which may exceed considerably the stress imposed by most jobs performed by working people in America today. The farmer is particularly vulnerable to heat from the sun as well as heat generated by equipment, such as tractors, and threshers, during his busiest work season. Much can be done to reduce this stress by proper shading, by production of air movement, and by wearing light clothing, but *often the person most in need of these modifications is the one most reluctant to accept them.* Frequent rest periods for workers exposed to high environmental temperatures and humidities are also helpful in reducing the physiologic stresses imposed, and often permit a patient to continue on a job which would otherwise be impossible.

Although information on the energy costs of various activities and jobs is generally useful, it may not help the physician in his attempt to determine if a patient can perform a specific job safely and productively The ability of a person to perform a particular job will depend more on his temperament, skill, emotional reaction to the task, and his experience than on the energy requirement of the job. When the physician is in doubt, it is sensible to permit the patient to continue in, or return to, his usual activities unless a definite reason for prohibiting such activities exists. Following return to activity, if the physician observes a working pulse rate in excess of 120 when the patient has a job which requires an energy expenditure of not more than about 2 or 3 calories per minute, and if the environmental temperature and humidity are moderate, then an undetected or inadequately treated cardiovascular abnormality, sustained anxiety, or a limited cardiac reserve is probably present and the situation should be re-evaluated. Consideration of the patient's psychologic or emotional state is of the utmost importance. Often it will be found that the emotional problems are of greater importance in rehabilitation than the physical limitations which the patient may have. Some physicians believe that individuals with specific types of cardiovascular disease (*i.e.*, hypertension and coronary disease) may have personalities or emotional problems peculiar to those diseases. This opinion is not generally shared, but there is little question that the cardiac patient is often presented with considerable psychologic stress relative to the threat of sudden death as well as the

threat to his psychologic and physical well-being, ease, and security. Also, there is no question that the physician who has knowledge and appreciation of the psychologic problems of the cardiac patient will be more effective in rehabilitating his patients than is the physician who does not consider these problems of importance. In evaluating the patient's psychologic or emotional state, it is important to permit him sufficient time to relate the details of his illness and of his concern about himself, his family, his job, and his future. When this is done, it is seldom necessary to have psychologic testing or psychiatric consultation to perform an adequate psychologic assessment of the patient.

When return to work is considered, it has been found that the patient's attitude about this may be of considerable importance. A simple method has been evolved to classify patients' attitudes toward work, and this has been found to correlate rather well with success or failure in vocational rehabilitation. The classification is as follows: (1) good: actively seeking employment and cooperative in attempts to help him; (2) fair: the will to work but doubtful of his ability to do so; (3) poor: not seeking work and maintaining he had difficulty in working; and (4) bad: obstructive of attempts to find him work and claiming his heart disease made him unfit to work. Two-thirds of the patients with a good or fair attitude were placed in productive employment, while only one-third of those with a poor attitude and none with a bad attitude were successfully placed.

The patient's attitude toward work, his fears, and neurotic traits, as well as other psychologic characteristics, are of prime importance in cardiac rehabilitation, and they may be summarized in the term *motivation*. If the psychologic assets are positive and the patient is strongly motivated, much can be accomplished by the individual, even in the presence of severe, physically disabling heart disease. If the patient is not motivated, the physician will accomplish little, even when the patient has little or no physical limitations due to his disease.

In evaluating the emotional status of a cardiac patient, especially a child, the physician must give due consideration to the family. Often the family will make the difference between success or failure in rehabilitation. If the members are understanding and cooperative, they can aid immeasurably, but, if they are fearful, overprotective, or rejecting, the efforts of the physician and all others who attempt to assist the patient in his rehabilitation may meet with failure.

The medical and psychologic aspects of rehabilitation of the patient with cardiovascular disease have received considerably more attention than have many of the sociologic aspects. Although many complex social factors are important in cardiac rehabilitation and should be considered, the most important is an opportunity for the patient to achieve practical and realistic goals. Often the limitations placed on the cardiac patient, young and old, by his physician severely restrict the opportunities available, and it is important for the physician, before he advises restrictions, to consider the physical, psychologic, social, vocational, and economic factors involved, as well as the likely consequence of his advice.

There are multiple problems that may arise in each individual with

heart disease, particularly those with differing etiologic types of heart disease, such as rheumatic, coronary, or hypertensive. For the youngster who has recovered from rheumatic fever, the important considerations may be education, physical activities, home environment, and penicillin prophylaxis. For an adult who has recovered from a myocardial infarction and who wishes to return to work, the important considerations may be his emotional reactions, his functional capacity, the characteristics of his job, the operations or activities involved in the job, the environmental conditions, the social and psychologic pressures, the wages, and his previous vocational experience and training, as well as his adaptability and interests There is an infinite variety of examples that could be used to illustrate this point, but, in general, the multiple problems involved can be solved, and rehabilitation of the great majority of cardiac patients can be successfully accomplished if the attending physician will keep in mind the general principles which have been outlined in this discussion and does not hesitate to ask for assistance in situations where he cannot provide the patient with the services necessary to accomplish his rehabilitation.

HEMIPLEGIA

Of all the clinical entities which face the practicing physician, one of the most difficult and neglected is hemiplegia. Today, it is estimated there are over 1,800,000 hemiplegic patients in the United States. Some idea of the magnitude of the problem is shown by the fact that "stroke" is the third major cause of death in the United States, ranking only behind heart disease and cancer. Proportionately to their populations, these same figures would apply roughly in the other nations of the world where the life span is approximately the same as that in the United States (Netherlands, Sweden, Norway, Israel, England, New Zealand, and Canada) and to a slightly lesser degree in those nations whose people have a shorter period of life expectancy. The objective of all who are concerned with the problem of the cerebral vascular diseases is to prevent the diseases that ultimately result in "stroke." Until this goal is reached, the practicing physician will be faced with the problems of the long-term management and rehabilitation of the patient with hemiplegia. Initially, medical and surgical *therapies will, of necessity, take precedence over rehabilitation, but even* in the period when the physician's efforts are directed toward saving the patient's life, he should not lose sight of the ultimate goal of rehabilitation. The physician's attitude during this period and the atmosphere which he helps to create may be decisive factors in the patient's motivation and, hence, in his eventual rehabilitation.

The physician's attitude toward and enthusiasm for rehabilitation will give him results superior to those of the physician who applies the same methods but who does so without hope. Unfortunately in the past, the medical attitude toward the hemiplegic has been one of hopelessness and passive acceptance. Hemiplegics have filled the back beds of our medical wards, the back bedrooms of our homes, and have crowded the few available nursing homes and institutions for custodial care. With a dynamic approach, the patient with hemiplegia should not be given up as a lost cause.

Recent spot-checks on the results of dynamic rehabilitation programs have shown that 90 per cent of all hemiplegic patients can be taught ambulation, self-care, and urinary and fecal continence, and 50 per cent can be taught to do gainful work. Further, it has been shown recently in a well-controlled objective study that such programs can result in an increment of over 125 per cent gain in ability to perform activities of daily living over nontreated subjects with smaller but significant gains in muscle strength and range of motion as well. For a program to be effective it must provide motivation and training opportunity. Motivation is not difficult if there is adequate opportunity afforded the patient.

The steps necessary for dynamic rehabilitation are: (1) evaluation of the disability; (2) development of a definitive prescribed program designed to meet the physical, emotional, social and vocational needs of the patient.

Evaluation of the Patient

Evaluation is the initial step in the patient's rehabilitation. The purpose of this examination is to assess the patient's medical and neurological status, his physical capacity and his over-all rehabilitation potential in order to determine the goal to be set for the patient and the procedures to be followed in order to achieve this goal.

There are five types of essential components for the rehabilitation evaluation of the hemiplegic patient: (1) medical and neurological, (2) functional (physical capacity), (3) speech (ability to understand and use language), (4) psychological, and (5) social-vocational. Under certain circumstances the evaluation may have to be carried out entirely by the family physician. It is much preferred, however, if the services of a neurologist and a physiatrist are available, that they may be properly utilized. The advice of a psychiatrist may also be needed and, under certain conditions, various other medical specialists, such as neurosurgeon, ophthalmologist, urologist, radiologist, and anesthesiologist, may be required for proper evaluation and treatment

For evaluation and treatment the team approach has proved far more successful than the utilization of separate services. The members of this team will vary under the conditions existing in the patient's own community, but ideally there should be family physician, neurologist, physiatrist and other medical specialists as needed, physical and occupational therapists, speech therapist, psychologist, medical or psychiatric social worker, and vocational counselor.

Physical Capacity: An estimate of the patient's physical capacity is made in order to determine the need for physical and occupational therapy and to aid in the assessment of the patient's rehabilitation potentials.

At the Institute of Physical Medicine and Rehabilitation of New York University-Bellevue Medical Center we assess the patient's functional capacity by determining, through examination, (1) joint range of motion, (2) muscle strength, and (3) the ability of the patient to perform the activities of daily living, and charts are used to record the results of these examinations. When the information is recorded in this manner, it is possible for the physician to estimate rather quickly the over-all capacity

of the patient for physical activity and the needs of the patient for physical and occupational therapy and for retraining in the activities of daily living.

Disabilities: If treatment is started early, there should be no limitation of motion at the joints, and the affected arm and leg will be able to be moved passively through their normal ranges If, however, the patient is not started on rehabilitation without delay, contractures will usually result, especially at the shoulder.

A flaccid hemiplegia occurs only in a small percentage of patients. The usual spastic hemiplegia presents the following signs: The affected arm is internally rotated and adducted, and the forearm, wrist, and fingers are flexed. When the patient is asked to move the affected arm, he will elevate the shoulder and further adduct and internally rotate the arm. When the patient's leg is fully extended, voluntary dorsal flexion of the foot is impossible When, however, the knee is flexed and the patient flexes his hip against resistance, the foot will dorsiflex and supinate (Strumpell's sign).

Some individuals may have an angiospasm of the cerebral vessels and present a typical hemiplegia syndrome. In such instances there is usually a complete return of function in a few days. If a patient has a return of function in the upper extremity, the lower extremity will usually be found to be normal. If the muscle strength, range of motion, and activities of daily living are adequately evaluated and charted, the physician and therapist will have an excellent method of objective evaluation as to the deficiency and the progress of the patient.

Most patients are suitable for a training program of rehabilitation. Covalt has pointed out that "the physician who sees a hemiplegic patient the first time may utilize two simple tests to determine whether or not the patient will ever be able to walk again. First, is the patient able to move the arm on the affected side? We know that if he can move the arm on the affected side, he would be able to walk again, since the arm is practically always affected more severely than the leg. Secondly, is the patient able to move the leg on the affected side one inch off the sheet? Such a test indicates that he should have sufficient quadriceps power to learn to walk again"

Communication: One aspect of hemiplegia which is far too frequently overlooked is communication disabilities resulting from brain injury among a high percentage of hemiplegic patients, particularly those whose hemiplegia is of the dominant side. These communication problems may be of two kinds: aphasia or dysarthria.

Aphasia: This is a language disability which affects one or more of the following: speaking, reading, writing, and understanding Aphasia may also involve difficulty in calculation or in using gestures. The four types of aphasia are described in the adjacent chart

Patients who have hemiplegia with accompanying communication difficulties are classified, after testing and evaluation, on the basis of the aforementioned language disabilities. It must be remembered that aphasia can only apply to patients with known brain injury.

The range from mild to severe difficulty is very wide among aphasic patients. Therefore, the term *predominantly expressive* may be applied to

Possible Predominant Symptoms of Four Types of Aphasia

	Expressive Symptoms	*Receptive Symptoms*
Predominantly expressive	Mild to severe difficulty in using gestures with or in place of speech, naming objects, speaking phrases and sentences, carrying on a conversation, putting thoughts into writing.	Any receptive deficiencies may exist but will not be as marked as expressive deficiencies
Predominantly receptive	*Any expressive deficiencies* may exist but will not be as marked as receptive deficiencies	Mild to severe difficulty in recognizing people, recognizing objects, understanding speech, understanding written language.
Expressive-receptive (mixed)	All predominant expressive symptoms	All predominant receptive symptoms
Global	No apparent ability to express oneself by gesture, speech, or writing	No apparent understanding of spoken or *written* language.

(Courtesy of *World-wide Abstracts*, Warner-Chilcott Laboratories)

(1) an individual who has only occasional difficulty in finding an appropriate word and may be slowed down in his ability to write words, as well as (2) an individual who is totally unable to express his thoughts in written or spoken words. In the first example, the patient described might still be capable of adequate on-the-job performance despite his language disability. It is probable that the patient in the second example will not be able to work and will be forced to lead a sheltered life at home or in an institution.

It is essential that the aphasic patient's functional language ability be appraised at the time of evaluation. The language demands of daily life, *e.g.*, telephoning, reading street signs, comprise the basis for this functional evaluation and for future therapy. Obviously, it is considerably more important for the aphasic patient to be able to say his name, to sign a check, and to ask for a drink of water, than it is for him to be able to recite the alphabet, spell a given list of words, and diagram sentences for their grammatical components.

At evaluation the patient's ability to meet the language demands of daily life are classified according to the following functional levels (from highest to lowest):

1. *Vocational adequacy in language.* Patients on this level are considered capable of qualifying for vocational placement, although not necessarily in their former vocation.

2. *Home adequacy in language.* Patients on this level are considered to have adequate language ability for functioning at home, *i.e.*, they are able to make their daily wants known and have sufficient receptive ability to manage the phone, read, understand signs, etc.

3. *Rehabilitation center adequacy.* Patients on this level are considered able to follow a rehabilitation program. They have adequate comprehension to permit attendance in group and individual classes, can use the elevator without assistance, and can follow nurses' and therapists' instructions.

4. *Institutional adequacy in communication.* Patients on this level are unable to perform in any of the higher level functional activities.

Dysarthria. Dysarthria is a speech disability based on motor dysfunction of the speech musculature. This condition may affect the production of certain speech sounds, the rate of speech, voice quality, phonation, rhythm, articulation, or any other aspects of speech dependent on motor ability. Some dysarthric patients may be so severely deficient in their speaking ability that they are "mute" or unintelligible. There are mild cases of dysarthria where the patient only has a slight difficulty in speaking distinctly.

The principal goal of therapy for the patient with dysarthria is to increase the intelligibility of speech To accomplish this the following technics may be used: imitating and practicing specific sounds before the mirror; repetitive exercises to improve voice quality, resonance, phonation, or articulation; using the tape recorder for critical self-analysis of speed, performing certain physical exercises to increase the accuracy and speech of tongue, lips and jaw movement These therapeutic technics can be of increased benefit to the patient if they are supplemented by home practice. The potential for the functional recovery of speech skills in these patients is usually rather good. Compensatory movements which are nearly normal can often be taught to the dysarthric patient, and many of these individuals are able to return to their former vocations following a period of speech therapy.

The differential diagnosis between dysarthria and aphasia is especially important since treatment and functional potential in these two disabilities differ It is recommended that all hemiplegic patients, who exhibit difficulty in communication, be evaluated by a professional speech therapist. With this appraisal as a base-line, formal speech therapy technics and plans for a home program can more efficiently be devised for the patient's recovery. The fact that large numbers of hemiplegic patients with difficulty in communication have recovered functionally should encourage professional workers in allied fields to refer patients for evaluation and treatment whenever possible.

Psychological, Psychiatric and Social Evaluation: Psychological and psychiatric evaluations of the hemiplegic patient are necessary to determine the degree of organic brain damage present, to assess the over-all

adjustment of the patient, and to estimate the prognosis for readjustment following treatment. The Department of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center, has recently completed a retrospective evaluation of 250 patients who had had strokes of apoplexy and were seen on the Physical Medicine and Rehabilitation Service at Bellevue Hospital. The average age of the group was sixty-three years, the average time which elapsed from stroke to rehabilitation training was nine months, and the average time in rehabilitation training was seven weeks

The purpose of this study was to correlate the status of these individuals two, three and five years after their rehabilitation training. It was found that the success of rehabilitation had no correlation whatsoever with the severity of the neurologic insult.

In the group were some patients who remained completely hemiplegic and who required long leg-braces or were confined to a wheelchair but lived useful, productive and happy lives; there were others who functioned physically, emotionally, socially and vocationally at a low level with disabilities consisting of slight residual paralysis in the hand. There was highly significant correlation on three factors. The patients did well, were able to get out of the hospital and live non-institutional lives, if (1) they had a job to which they could go, (2) they had a home to which they could go, and (3) they had someone who loved them.

It is, of course, most helpful if the physician can have the services of a psychologist for psychological evaluation. Many times, however, such specialized assistance is not available or the physician must make an evaluation of the patient's psychological and psychiatric status from on-the-spot clinical observations. This should be done through observations and notes on the patient's status with regard to: (1) memory for recent and past events, (2) orientation for time, place and person; (3) ability to perform simple calculations; (4) concentration and attention span, (5) mood; (6) hallucinations or delusions; (7) behavior; (8) intellectual capacity to handle abstract material; (9) ability to follow directions or instructions; (10) cooperation; (11) relationship to others; (12) adjustment to social needs, and (13) degree of independence prior to illness.

It is also important to determine if the patient has any disturbance in his body image. The patient may deny any change in body image, may deny that any paralyses or even any illnesses exist.

The emotional readjustment of the hemiplegic patient is difficult because he must meet a major physical handicap with a damaged nervous system and a diminished capacity for adjustment. The pre-illness personality is, of course, of major importance in this adjustment, and it is important for the evaluation to include an assessment of pre-illness personality.

Anxiety, depression, irritability, emotionality, apathy, rigidity of behavior are all likely to be encountered in hemiplegic patients. Their importance in each case must be evaluated because they may greatly retard progress in rehabilitation if they are not recognized and given proper consideration. The social status and adjustment of the patient are consid-

ered within the framework of the patient's family and community. If the patient is evaluated and treated as a hemiplegic the ultimate objectives will seldom be achieved.

The areas of importance socially which require evaluation are health, personal adjustment, interpersonal relations, housing, vocation and economic status. It is important to appreciate that ultimate success or failure in rehabilitation is determined not by the patient's accomplishments in physical retraining but by his accomplishments in his home and in the community.



FIGURE 1 By raising and lowering the unaffected leg against the resistance of the sandbag, the patient strengthens his quadriceps muscle to provide the necessary support needed for ambulation and step-climbing (*World-wide Abstracts* Photo courtesy of Warner-Chilcott Laboratories)

The Rehabilitation Program

The objectives of a program of rehabilitation for hemiplegic patients are: (1) to prevent deformities, (2) to treat deformities if they occur, (3) to retrain the patient in ambulation and elevation activities, (4) to teach the patient to perform the activities of daily living and working with the unaffected arm and hand, (5) to retrain the affected arm and hand to the maximum capacity, and (6) to treat facial paralysis and speech disability if present.

Prevention of Deformities: The spastic hemiplegic patient, when lying in bed, holds the upper extremity in adduction and internal rotation with

the elbow, wrist and fingers of the affected part in a flexed position. The affected lower extremity is usually flexed, and adducted at the hip joint, the knee is flexed and the ankle is plantar-flexed and supinated. If treatment is started within a few days following the cerebral vascular accident, there is no need for any special procedures to protect the affected limbs. If, however, the patient must remain in bed for a period of time, procedures must be instituted to prevent deformities.



FIGURE 2 Training in the activities of daily living must include learning to transfer independently to all types of chairs (*World-wide Abstracts* Photo courtesy of Warner-Chilcott Laboratories)

A posterior ankle splint is used to prevent shortening of the heel cord. A pillow in the axilla will prevent adduction and internal rotation of the shoulder joint—a frequent residual deformity in hemiplegia. Passive movements of the arm in abduction, external rotation, and in the overhead position should be performed several times a day to prevent a "frozen shoulder."

Treatment of Deformities: The principal deformities which may occur are "frozen shoulder" and a shortened heel cord.

The use of heat and massage to the arm and shoulder is of value in preparing the part for stretching. Passive movements of the shoulder are useful in increasing the range of motion. These movements can be performed by a therapist, nurse, or by the patient himself (see Exercises I and II, p. 1206F).

A short heel cord seldom requires operative procedures. The heel cord usually can be lengthened by means of stretching and a short leg brace with a 90- to 110-degree stop at the ankle to maintain the gains made by stretching and ambulation.

Ambulation: Flexion and extension movements at the hip and knee can usually be performed by the spastic hemiplegic subject who is started on early ambulation. When, however, the hip and knee are flexed, as in



FIGURE 3 The patient practices putting on her leg brace with the unaffected hand All activities which are usually done with two hands are practiced with the unaffected hand. The brace which this patient is wearing is a short leg-brace, using a 90-degree stop to counteract foot drop with a pronator strap to counteract pronation of the affected foot (Courtesy of *Health News*, State of New York, Department of Health)

walking, the foot dorsiflexes and supinates. The patient is usually afraid to place the supinated foot on the floor because of the danger of injuring the ankle or falling. To prevent this foot movement, he walks with a fixed knee joint and circumducts the lower extremity This slow, awkward gait, if used for a time, will become an habitual pattern of walking which will be cumbersome, fatiguing, and difficult to correct.

A double bar, short leg brace with a stirrup attachment, 90-degree ankle stop, and a supinator "T" strap should be prescribed to prevent plantar flexion and supination of the foot and give the patient confidence so that he will flex his knee and hip. With the brace and a cane in the unaffected hand for balance, most hemiplegic patients soon learn to walk unaided

A patient with flaccid hemiplegia will be unable to make a voluntary movement when in the supine position. If, however, the patient is supported in the erect position with the affected lower extremity on the floor, he will flex and extend the leg as in walking and be able to bear his body weight. The sensory contact of the foot on the floor stimulates the reflex pattern of walking. Ambulation should be the first procedure in a rehabilitation program, because it can be accomplished by the majority of patients. Some patients, especially those in the younger age groups, learn



FIGURE 4 Extension at the elbow and flexion at the shoulder joint are administrated by the physical therapist (Courtesy of *Health News*, State of New York, Department of Health)

to walk with a good reciprocal pattern without the aid of a cane. No patient, however, seems to learn the reciprocal arm pattern without special training.

The normal pattern of walking is to move the right arm and left leg forward and then the left arm and right leg. The hemiplegic patient walks with the affected arm motionless, adducted, and partially flexed at the elbow. It is necessary to break this pattern of walking if the patient is to have the appearance of being normal. The following methods are recommended for retraining in the normal pattern of walking:

Retraining in Walking: Method I: *Equipment:* Parallel bars with a sliding apparatus over the bars to prevent excoriation of the hands. (Round cardboard boxes with the ends removed can be placed over the

bars. The open sides can be taped together with adhesive tape to hold them on the bars.)

Position: The patient stands between the bars with one hand on each bar. The affected hand is placed on the movable box and may be tied if necessary.

Instructions: Step forward with the right foot and move the left hand forward along the bar. Step forward with the left foot and move the right hand along the bar. Repeat five times, several times a day up to fatigue.



FIGURE 5 A warm whirlpool bath (102° F) for the affected hand is given for relaxation, stimulation of blood circulation and alleviation of pain (Courtesy of *Health News*, State of New York, Department of Health)

Retraining in Walking: Method II: *Equipment* None.

Position The patient stands with the feet together and arms at the side

Instructions. Step forward with the right foot and swing the left arm forward and point to the right foot Step forward with the left foot and swing the right arm forward and point to the left foot The opposite arm and leg must be moved together and remain parallel at all times. Repeat five times, several times a day.

For children a red ribbon is tied to the right wrist and left foot, and a yellow ribbon to the left wrist and right foot. The children are instructed to move the red ribbons forward and then the yellow ribbons.

When the patient can walk with the reciprocal pattern of arm and leg movements and talk with the instructor, the pattern is formed and the patient has been retrained.

The Unaffected Arm and Hand: As a return of function in the affected upper extremity cannot usually be expected for a long period of time, if ever, it is essential to teach the patient to care for his daily needs with the unaffected arm. "A lobster can grow a claw, a man cannot, but he has what a lobster does not have, a brain to meet the needs of the situation."

A right hemiplegia in a right-handed person is a serious disability because of the sensory and motor aphasia and the lack of skill in the left hand to perform the activities essential for daily living. The training of



FIGURE 6 With the use of a simple pulley device, the hemiplegic patient can independently perform exercises to maintain range of motion in the affected shoulder (*World-wide Abstracts.* Photo courtesy of Warner-Chilcott Laboratories)

the left hand should be started early, as the patient must become left-handed if he ever hopes to care for his daily needs. Simple tasks in eating and dressing should be started. Left-hand writing must be practised, as this is an important means of communication, especially when speech is affected.

The Affected Arm and Hand: Training of the affected arm is started while the patient is developing one-handed skills with the unaffected arm If the arm is flaccid, a re-education program similar to that used in poliomyelitis should be started. Many of these patients have a complete return of function if the muscle re-education is given carefully over a long period of time. The rehabilitation of the spastic arm should start at the shoulder. The most difficult shoulder movement for the patient to regain is external

rotation. Flexion and extension of the forearm likewise are difficult for the spastic hemiplegic patient to perform. When asked to flex the elbow, he elevates the shoulder and adducts and internally rotates the arm. Pronation and supination of the hand are usually impossible since these are some of the last movements learned by man and, hence, the last to return. Internal and external rotation of the arm are primitive movements and the patient attempts to substitute these movements for pronation and supination. The fingers and thumb are usually flexed tightly. If the



FIGURE 7 Walking in the parallel bars is practiced in preparation for walking with a cane A short leg brace is worn by the patient on the affected leg to counteract foot drop (Courtesy of *Health News*, State of New York, Department of Health)

fingers and thumb are forced open, they can be flexed, but active extension movements are usually impossible. On yawning, the fingers of the hand actually extend.

The exercise program for retraining the affected arm depends upon the patient. As Deaver stresses, results cannot be expected by having a therapist work on the patient. The therapist must work with the patient so that he understands the exercises, their purpose, and how they are to be performed to achieve maximum results. Occupational therapy is of particular value in the retraining of the arm, as it combines exercise and retraining with interesting activity. Care must always be taken to insure that the activity involved in the occupational therapy is that which will

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provide the maximum functional value to the patient in terms of later skills of daily living.

Exercise I: Flexion of the Arm at Shoulder: *Purpose:* To maintain or increase the shoulder movements and to strengthen the shoulder girdle muscles.

Position: The patient sits on a chair or lies supine in bed.

Instructions: The patient grasps the wrist of the affected arm with the fingers of the unaffected arm. He raises the arms forward, upward, as far overhead as possible. He repeats this exercise five times on the hour.

Exercise II: Flexion and Extension of the Forearm: *Purpose:* To obtain full range of motion at the elbow and active flexion and extension of the elbow without adduction.

Position The patient sits on a chair, elbows close to side of body, and palms of the hands together with the ulnar side of the hands resting on the affected knee.

Instructions: The patient flexes the forearms and touches the chin. He repeats this exercise five times on the hour. The patient may have difficulty in opening the spastic fingers with the unaffected fingers, but the best possible position should be obtained. This is a good exercise in preventing flexion contractures of the fingers

It is an interesting neuromuscular phenomenon that when the hands are clasped, or even brought in contact, the elbow can be flexed without any adduction of the shoulder. When the hands are separated and the patient is asked to flex the elbow, the affected arm will adduct and rotate inward

Exercise III: Flexion and Extension of the Forearm and Supination and Pronation of the Hand: *Purpose:* To combine flexion and extension of the elbow with supination and pronation of the hand.

Position. As in Exercise II.

Instructions: The patient places his palms together as in Exercise II, flexes the forearm, and supinates the affected hand as he raises it to the chin. On extension of the forearm the hand is pronated. The patient repeats this exercise five times on the hour.

The tight supinator muscles of the affected arm can be stretched by the unaffected hand. Flexion of the elbow with supination of the hand are the most useful movements in performing the activities essential for daily living.

Exercise IV: Flexion of Forearm and Arm of the Affected Side: *Purpose:* To combine these flexion movements so that the patient may use the hand in daily activities, such as holding paper down while writing.

Position: The patient sits on a chair in front of a table.

Instructions: The patient flexes the forearm to table level and then flexes the arm so that the forearm rests on the table. These movements must be performed without elevating the shoulder or adducting the arm. The patient repeats this exercise five times on the hour. The habit of routinely keeping the hand in the lap mitigates against re-education. It must be placed in the position for finger action.

The wrist, if not flexed, needs no special training. There are very few activities which cannot be performed even with a fixed wrist. The functional use of the hand has been increased in several young patients with extreme flexion of the wrist by fusing the wrist joint. A cock-up splint should be used if there is extreme flexion of the wrist, and this should be combined with a "pancake" splint if the fingers are tightly flexed.



FIGURE 8 Finger contractures can be prevented by extension of the fingers and thumb of the affected hand by the unaffected hand periodically (Courtesy of the Institute of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center)

The fingers of the spastic hemiplegic patient are most difficult to re-educate for any useful purpose. If good function is ever attained it represents a great cost in time and concentrated effort by the patient. In the aged with advanced cardiovascular disease, it is seldom worth the effort. One should not, however, have the patient give up hope of ever using the fingers. He must be made to understand that the movements of the fingers depend upon the proper functioning of the shoulder, elbow, and hand, and placing the hand in positions for purposeful movements. Exercise for the fingers should be purposeful and wherever possible should be in terms of functional activity in which the patient relearns a practical skill which will prove functionally useful, such as buttoning, manipulating zippers, handling objects, and self-care activities. The following exercises for the fingers can be used for the purpose indicated:

Exercise V: Extension of Fingers and Thumb: *Purpose:* To prevent finger contractures by extension of fingers and thumb.

Position: The patient sits on a chair.

Instructions: With the fingers of the unaffected hand the patient extends each finger and the thumb of the affected hand. He repeats this exercise five times on the hour.

Exercise VI: Extension of Fingers and Thumb: *Purpose:* As in Exercise V.

Position: The patient sits on a chair with his hand resting in pronation on a table and his fingers extended as far as possible.

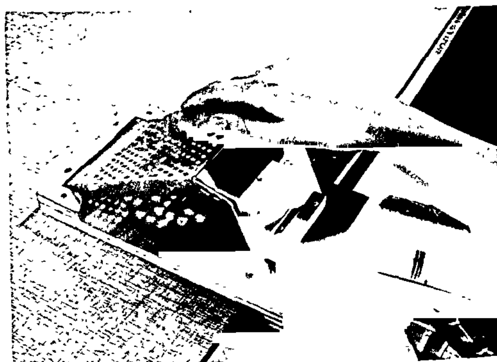


FIGURE ... various ... tute of ... Medical Center)

Instructions. The patient presses backward and downward on the table surface so that the palm of the hand is in contact with the table. He repeats this exercise five times on the hour.

Exercise VII: Extension and Flexion of Fingers and Thumb: *Purpose.* To produce passive movements of extensors and active movements of flexors.

Position: As in Exercise VI, with a pencil resting on the table under the palm of the hand.

Instructions: The patient presses backward and downward on the dorsal surface of the hand so that the palm of the hand is in contact with the

table. He releases the pressure, flexes the fingers, and picks up the pencil. He repeats this exercise five times on the hour

Self-help Devices: In the rehabilitation of the patient with hemiplegia, it is readily apparent that numerous factors will determine the degree of results obtained in ability to perform the activities of daily living. Some patients will achieve a surprising degree of recovery of function, others will be left with varying degrees of permanent residual disability. Even with these latter patients much can be done with the use of uncomplicated mechanical devices which will enable the patients to perform the simple acts of daily living either independently or with a minimum of assistance from other persons. Such devices should be used only when necessary and, before a device is given to a patient, retraining in the activity should be attempted.

The disabilities which the hemiplegic patient faces in managing the activities of daily living are those which require compensation for the loss of the use of one upper and one lower extremity. Because of involvement of the hand, many activities usually performed with both hands must be performed with one. Involvement of the lower extremity obviously makes standing, walking, and climbing difficult. Patients with these defects should have their programs specifically planned to master, as far as possible, these deficiencies or, if not able to master them, to circumvent them.

Many devices are available commercially or can be adapted so that many of the activities of daily living, such as dressing, eating, personal hygiene, communication, homemaking and recreation, can be performed with the unaffected hand. If the patient needs a wheelchair for permanent use or during the early phase of his rehabilitation, the chair selected should be equipped with a one-arm drive and have brakes. The one-arm drive has both hand-rims on one side with a connecting rod to the axle of the opposite wheel, making it possible to propel the chair with the one good arm. The removable wheelchair arm permits easier transfer to bed, toilet and car by allowing the patient to slide across

Rehabilitation in Communication: The principal factors which affect progress during rehabilitation of communication are: (1) the patient's motivation and "need" for speech, (2) the extent of damage and severity of symptoms, (3) the patient's ability to learn new material, and (4) attitudes of the patient's family toward his communication problems. In addition, the patient's personality before the onset of aphasia seems to have an effect on recovery of his powers of communication. For some patients who were very withdrawn premorbidly, the effect of an aphasic condition appears to be minimal—their "need" for language is limited. On the other hand, persons who were greatly dependent on communication premorbidly for their social and intellectual welfare are more likely to feel a greater demand for communication

Our experience shows that with few exceptions all aphasic patients who have had the benefit of language retraining procedures will make some measure of progress. In good candidates, it can be anticipated that the patient will graduate from one functional communication level to

another during the course of treatment. In a smaller number of cases, we can expect almost complete return of language function.

Functional communication recovery is the primary goal of a communication rehabilitation program. Patients who learn communication skills, which they can use only under certain clinical circumstances or which they can produce only as automatic responses to specific stimuli, are not considered to be making progress. It is the improved ability to use language appropriately when there is a demand for it, without assistance and under average circumstances that comprises progress.

Most aphasic patients who are admitted to the communication rehabilitation unit are just beginning to use nouns. A large number of the technics devised for use in aphasia retraining, therefore, are based on learning at the "naming level." Every sensory avenue is utilized to teach the patient language. His hearing and vision are employed. On the naming level the patient is familiarized with the language symbols through seeing the live objects which the noun represents and seeing the word which is applied to the object, hearing the word repeated by the therapist, copying the word, matching the word with the appropriate object, and writing the word from dictation.

The proper selection of the vocabulary to be taught to the aphasic patient is essential to a sound retraining program. This is especially true when the patient will only be able to learn a limited vocabulary. If the nature of the vocabulary is not functional and realistic, much valuable therapeutic time will be wasted. A basic word list of 100 nouns has been designed for this purpose.

The physical factors conducive to successful aphasia rehabilitation should be borne in mind when the retraining program is initiated. Sessions should be short and frequent rather than long and infrequent. A quiet, undistracting setting is advisable. The atmosphere for therapy should be permissive and each session should end on a successful note for the patient.

It is the goal of therapy that the patient's production of each word be as close to normal as possible; however, little or no attention is given to pronunciation. It is more important for the aphasic patient to be fluent than perfect in his pronunciation. When a patient has learned a majority of the 100 nouns in the basic vocabulary list, he is then taught verbs in combination with the nouns already learned, *e.g.*, pencil—write, spoon—eat. The order of teaching words according to their difficulty is: nouns, verbs, adjectives, conjunctions, pronouns, articles, and prepositions In general, the "pictureability" of a word and its familiarity to the patient determine its difficulty. The names of objects, therefore, are easiest to teach the aphasic patient. On levels above the noun-verb level those teaching materials designed for teaching English to foreign students are useful.

Contemporary thinking in the field of aphasic rehabilitation would seem to indicate that there is a great correlation between language stimulation through listening and language learning. Ear training through repetitive listening can be accomplished by (1) the therapist's frequent repetition of words, and (2) the use of a machine which repeats words from specially

designed tape-recorded cards. All types of auditory training should generally precede actual speech training and should be used as a valuable supplement to formal speech training.

It is difficult to ascertain in any given case of aphasia how much therapy will be necessary for the patient to reach his maximum level of language proficiency. Retraining the aphasic patient is a slow process which usually takes many months. Experience tells us that a trial period of therapy is indicated for all aphasic patients in order to determine whether or not treatment will be of benefit. In many cases, once therapy has been initiated it is possible for the aphasic patient to follow a home program under the supervision of a trained therapist or in conjunction with a formal speech therapy program.

CONCLUSION

Hemiplegia presents one of the most challenging problems in medicine today, both in total numbers and in therapeutic complexities. Many patients with hemiplegia do not achieve a level of function which permits them to be employed or to make an economic contribution to the family. With adequate rehabilitation, they can, however, achieve a goal of self-care, independence and dignity. Much of their success in attaining this goal is dependent upon the physician's own attitude and enthusiasm for both rehabilitation and his hemiplegic patients.

REFERENCES

1. Buchwald, Edith· Physical Rehabilitation for Daily Living New York, Blakiston Division, McGraw-Hill Book Co , 1952
2. [illegible]
3. [illegible]
4. Lane, Morton· Rehabilitation Monograph XVI. The Effect of the California Workmen's Compensation Law upon the Employment of the Handicapped New York, Institute of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center, 1958
5. Rusk, Howard A , Kristeller, Edith L , Judson, Julia, Hunt, Gladys M., and Zimmerman, Muriel E · Rehabilitation Monograph VIII A Manual for Training the Disabled Homemaker. New York, Institute of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center, 1955
6. Rusk, Howard A , and Taylor, Eugene J.: Living with a Disability. New York, Blakiston Division, McGraw-Hill Book Co., 1953
7. Rusk, Howard A , *et al* . Rehabilitation Medicine. St Louis, The C. V. Mosby Co , 1958.
8. Self-help Devices for Rehabilitation Dubuque, Iowa, Wm. C. Brown, Publishers, 1958.
9. Strike Back at Stroke Public Health Service Publication No 596, Department of Health, Education and Welfare Washington, U. S Government Printing Office, 1958

Pages 1195 to 1206L replace former pages 1195 to 1205 © 1959

10 Taylor, Martha L Understanding Aphasia: A Guide for Family and Friends New York, Patient Publication No. 2, Institute of Physical Medicine and Rehabilitation, New York University-Bellevue Medical Center, 1958

11 Taylor, Martha L, and Marks, Morton Aphasia Rehabilitation Manual and Therapy Kit New York, Saxon Press, 1959

12 White, Paul Dudley, Rusk, Howard A, Lee, Philip R., and Williams, Bryan: Cardiovascular Rehabilitation New York, Blakiston Division, McGraw-Hill Book Co, 1957.

13 White, Paul Dudley, Rusk, Howard A, Lee, Philip R, and Williams, Bryan Rehabilitation of the Cardiovascular Patient New York, Blakiston Division, McGraw-Hill Book Co., 1958

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39

Form of the Electrocardiogram*

Introduction: This chapter is devoted to a consideration of the significance of the form of the electrocardiogram. Inasmuch as the cardiac irregularities are discussed elsewhere in this volume, no reference is made here to alterations in the contour of the electrocardiographic deflections which depend upon changes in the site or mechanism of impulse formation or upon excessive acceleration of the heart rate, such as occurs in auricular flutter and paroxysmal tachycardia. In discussing the ventricular complex, it is assumed throughout that the ventricles are responding to stimuli of supraventricular origin.

NORMAL ELECTROCARDIOGRAM

In taking clinical electrocardiograms most physicians include the three standard leads originally adopted by Einthoven. In Lead I the galvanometer terminals are attached to the right arm and left arm; in Lead II, to the right arm and left leg; in Lead III, to the left arm and left leg. In each case the connections are made in such a way that relative negativity of the first-named extremity will produce an upward deflection in the completed record. The sensitivity of the galvanometer is so adjusted that a difference in potential of one millivolt is represented in the record by a deflection of one centimeter.

A typical example of the curves obtained from normal subjects is shown in Fig. 1. Although all of the leads depict the same series of events, they differ considerably in detail. In each lead the heartbeat is represented by a group of summits and depressions, as many as six distinct deflections, P, Q, R, S, T, and U may occur. In normal curves the summits P, R, and T are always present, but either or both of the depressions Q and S may be absent, and conspicuous U deflections are rarely seen. The first deflection, P, is associated with auricular systole and is often referred to as the *auricular complex;* Q, R, S, and T are ascribed to ventricular events and constitute the *ventricular complex;* U occurs in early diastole, and although its origin is not entirely clear, studies by Surawicz and Lepeschkin[1] and others suggest that low serum potassium may increase its size.

*This chapter was originally written by the late Frank N. Wilson, M.D., and in this revision much of the material he prepared is included, because it is quite pertinent and cannot be presented in better form. Several former sections no longer considered to be essential have been deleted, and much new material has been added.

Leads, other than the three standard leads, will be described later in this chapter, but since tracings obtained with leads of any kind show the same basic complexes and the same intervals, it is logical to discuss the normal values of the various waves and intervals to be found in all commonly employed leads at this point.

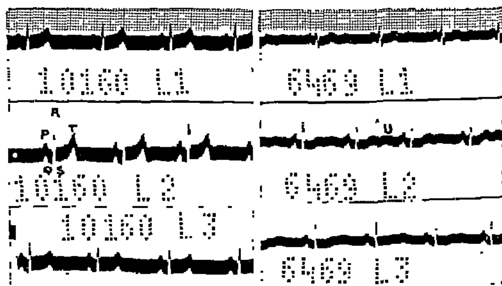


FIGURE 1 No 10160. Normal electrocardiogram The effect of introducing a potential difference of one millivolt into the circuit containing the patient and the galvanometer is shown at the left end of Lead III. In this curve and in those which follow a potential difference of one millivolt is represented by a deflection of one centimeter The vertical lines which cross the record mark intervals of 0 04 and 0 20 second No. 6469 A normal electrocardiogram showing a prominent U deflection. (Cyclopedia of Medicine, F A Davis Co)

It must be emphasized that the range of normal for these deflections and intervals is a broad one, and one must expect a rather wide zone of uncertainty between deflections and intervals which are obviously normal and those that are clearly abnormal. Kossmann[2] has summarized our knowledge regarding the normal electrocardiogram in an excellent article recommended to our readers.

The P-R Interval

This interval is measured from the beginning of the P wave to the onset of the QRS complex so that in many tracings the interval might properly be designated as the PQ rather than the P-R interval. It is a measure of A-V conduction time, and most of this interval is due to slow conduction of the electrical impulse as it passes through the A-V node. The interval is usually estimated from the standard leads, remembering that the first part of a small P wave (especially in Lead I) and the beginning of the QRS complex (particularly in Lead II) may be isoelectric. These peculiarities of the P waves and QRS complexes explain apparent variations in the P-R interval. The writers usually estimate the interval from careful inspection

of all standard leads. Occasionally, if the P waves are very small in the limb leads and larger in precordial leads, it may be best to use the latter for the measurement of the P-R interval.

In adults, the upper limit of normal for the P-R interval is 0.20 sec., although it may occasionally measure 0.21 or 0.22 sec. in individuals who show no other evidence of cardiac abnormality. In children the interval is shorter than in adults. Under the age of fourteen years an interval of 0.16 sec. may be abnormally long. In interpreting the length of the P-R interval it should be remembered that it often increases slightly with a decrease in heart rate.

Unusually short P-R intervals are most frequently found with anomalous A-V excitation (Wolff-Parkinson-White syndrome) and with A-V nodal rhythm, with the pacemaker in the upper part of the A-V node. In the former condition lengthening of the QRS interval, together with other peculiarities of the QRS complexes and, in the latter, inverted P waves in leads II, III, and AVF usually serve to make the cause for the short interval clear. Occasional records showing short P-R intervals that do not fit into either of the above mentioned groups are seen. Lown, Ganong, and Levine[3] have described tracings of this kind.

The QRS Interval

This interval is measured from the beginning of the QRS complex to its end, and the limb leads are usually employed for this purpose. The QRS interval often appears slightly longer in chest than in limb leads and perhaps in the future, when more data concerning the normal values for the QRS interval in precordial leads are available, they will be used for its estimation. It is possible that the longer QRS interval occasionally observed in chest leads is due, in part at least, to technical deficiencies in the recording instrument and the longer intervals are more apparent than real.

The upper limit of normal for the QRS interval in adults is usually considered to be 0.10 sec., but occasional tracings, taken from subjects without other findings pointing to heart disease, show slightly longer intervals. QRS intervals of 0.12 sec. or more indicate the presence of intraventricular block as a rule. The QRS interval is normally shorter in infants and children, varying from 0.04 to 0.08 sec., depending on their age.

The Q-T Interval

The duration of electrical systole, measured from the beginning of QRS to the end of T, varies with the heart rate. Various formulae which express this relation have been devised, and Bazett's formula, $(\text{Q-T}_c) = \frac{\text{Q-T interval}}{\sqrt{\text{R-R interval}}}$, has been widely used. Q-T$_c$, the corrected Q-T interval, shows considerable normal variation, but the writers agree with Kossmann[2] that 0.425 is the upper limit of normal for this quantity. Up to the present time, the length of the Q-T interval has not proved to be of great diagnostic importance, but striking prolongation of this interval without a corresponding increase in the duration of mechanical systole occurs when the blood calcium falls

to a very low level, as in hypoparathyroidism or nephritis. Prolongation of this interval has also been observed in bundle branch block, in complete A-V heart block, in coronary occlusion accompanied by very large inverted T deflections, and in cardiac failure. When serum calcium is elevated, as in hyperparathyroidism, the $Q\text{-}T_c$ becomes abnormally short, and Cheer and Dieuaide[4] many years ago observed a decrease in the Q-T interval after the administration of digitalis. Recent observations by Taran and Szilagyi[5] and Pokress and Goldberger[6] indicate that significant prolongation of the Q-T interval may occur in the presence of acute rheumatic fever.

Size of Deflections

Table I summarizes most of the available data concerning the size of the deflections occurring in electrocardiographic leads that are in common use. The figures given apply only to normal adults, twenty or more years of age, and as indicated below the table, are based on tracings taken by several investigators. Kossmann[2] and studies by Ziegler[7] give data on the size of deflections occurring in tracings taken from normal infants and children.

When the values given in the table are used, it must be remembered that some of the figures given, particularly those representing the maximal size of deflections, occur very rarely in normal individuals.

Discussion of Electrocardiographic Leads

Although many physicians still active remember the early years during which only the three standard leads of Einthoven were employed in clinical electrocardiography, the situation has changed greatly since the 1930's and some discussion of a number of basic matters relating to electrocardiographic leads, including vector methods, is clearly in order. The form of an electrocardiogram depends to a great extent on the type of lead employed in its registration, and some understanding of the behavior of different kinds of leads is important.

The number of different leads that may be used is nearly unlimited, but practical considerations make it desirable to employ no more than necessary for routine diagnostic purposes. The three standard leads give a reasonably good idea of cardiac e.m.f.'s oriented in a transverse or vertical direction, *i. e.*, in the frontal plane, but not for voltages having primarily an anterior-posterior orientation within the heart. The equilateral triangle concept of Einthoven has been described, and its validity discussed so frequently in electrocardiographic literature that it is not necessary to consider it in detail here It is important to point out, however, that, in spite of its inaccuracies, the equilateral triangle scheme has been and will continue to be a very important device in the understanding and intelligent use of the limb leads. It allows the electrocardiographer to interpret the limb leads in terms of voltages existing in the heart. All experienced workers in this field use the triangle in reading electrocardiograms and to this degree, at least, employ vector methods in their interpretations.

TABLE I

NORMAL ADULTS, TWENTY YEARS AND OVER, SUPINE. SIZE OF THE ELECTROCARDIOGRAPHIC DEFLECTIONS IN THE BIPOLAR EXTREMITY, AUGMENTED UNIPOLAR EXTREMITY, AND UNIPOLAR PRECORDIAL LEADS, IS GIVEN IN TENTHS OF A MILLIVOLT.

Lead	P				Q				R				S				RS or QR				S-T				T			
	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean	No. Cases	Min.	Max.	Mean
I	475	0	2.5	0.69	505	0	2.0	0.27	505	0.7	19.4	5.51	505	0	6.4	1.27	63	3.0	20.6	8.54	100	−0.3	0.9	0.11	505	−0.5	5.6	2.20
II	475	0	3.0	1.07	505	0	4.0	0.38	505	0.5	28.0	9.41	505	0	8.2	1.36	63	8.0	32.0	15.14	100	−1.0	1.0	0.21	505	0	8.0	2.67
III	475	−0.8	2.0	0.56	505	0	4.0	0.48	505	0	22.0	5.56	505	0	13.0	1.29	63	3.2	25.0	10.62	100	−0.6	0.8	0.04	505	−2.0	5.5	0.77
V_R	32	−1.0	−0.5	−0.63	62	0	8.0	2.48	62	0	3.0	0.90	62	0	11.0	3.01	62	3.5	12.0	6.50	32	0	0	0	62	−4.0	−0.5	−1.65
V_L	32	−0.5	0.5	0.07	62	0	1.5	0.16	62	0	7.0	1.21	62	0	7.0	2.04	62	0.5	8.5	3.37	32	0	0	0	62	−1.0	1.5	0.29
V_F	32	0	2.0	0.72	62	0	2.0	0.30	62	0	15.0	6.82	62	0	6.5	0.74	62	3.5	16.5	7.77	32	0	0	0	62	0	4.6	1.40
aV_R	411	−1.5	−0.1	−0.79	552	0	16.8	2.38	552	0	4.1	0.94	552	0	15.7	3.76	—	—	—	—	—	—	—	—	479	−5.5	−0.2	−2.40
aV_L	411	−1.0	1.4	0.51	552	0	3.5	0.27	552	0	10.1	2.61	552	0	11.3	1.35	—	—	—		—	—	—	—	479	−4.0	6.0	0.78
aV_F	411	−1.8	1.7	0.74	552	0	3.0	0.38	552	0	20.0	4.73	552	0	7.1	0.81	—	—	—		—	—	—	—	479	−0.6	5.2	1.85
V_1	371	−1.1	2.2	0.57	567	0	0	0	567	0	15.5	3.09	567	0.8	26.2	9.44	63	6.6	35.0	14.99	33	0	0.5	0.01	542	−4.0	12.2	0.84
V_2	371	−0.7	2.0	0.60	594	0	0	0	594	0	23.0	5.96	594	0	39.2	14.09	63	13.0	55.0	26.82	33	0	1.0	0.09	542	−2.6	18.0	4.70
V_3	371	−0.5	2.0	0.61	567	0	1.5	0.01	567	0.7	54.6	8.93	567	0	27.5	9.51	63	11.1	54.6	24.12	33	0	2.0	0.20	542	−2.0	21.0	5.16
V_4	371	−0.2	2.3	0.60	594	0	4.0	0.13	594	1.8	46.0	13.78	594	0	29.8	5.93	63	9.0	51.6	26.16	33	0	1.0	0.03	542	−0.5	17.0	5.06
V_5	371	0	2.4	0.56	567	0	3.4	0.43	567	0.4	33.6	12.01	567	0	16.1	1.96	63	10.0	36.4	19.31	33	0	0	0	512	0	11.0	3.83
V_6	371	0	1.8	0.54	564	0	2.7	0.44	564	2.0	22.6	9.68	561	0	14.3	1.00	33	7.0	24.5	13.93	33	0	0	0	512	0	6.9	2.80
V_E †	—	—	—	—	30	0	0	0	30	2.0	12.8	5.81	30	0	16.2	6.09	30	5.6	24.2	11.91	—	—	—	—	30	0.2	5.2	2.55

Table prepared by Criteria Committee of the New York Heart Association and reproduced from *Nomenclature and Criteria for Diagnosis of iseases of the Heart and Blood Vessels*. It is based on normal series studied by Kossmann and Johnston, Kossmann and Goldberg, Wilson and yboer; Vaquero, Limón, and Limón, Deeds and Barnes, Myers, Klein, Stofer, and Hiratzka, Sokolow and Friedlander; Kneese de Melo.

† V_E, lead from tip of the ensiform cartilage.

Unipolar electrocardiography has been very popular in recent years The term is strictly speaking a misnomer, since two electrodes must always be either directly or indirectly (i e., through a resistance network) connected to the body, and no scheme has yet been devised which will insure that one of these electrodes will have zero potential throughout the heart

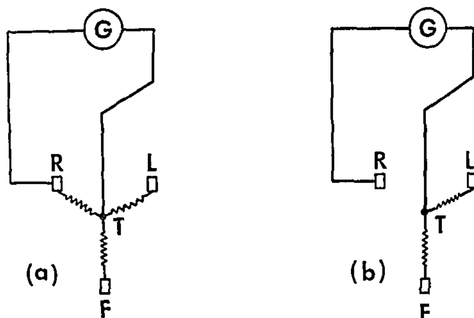


FIGURE 2 In (a) the electrocardiograph records Lead V_R, while in (b) the augmented lead aV_R is recorded

cycle. Nevertheless, the unipolar extremity leads (V_R, V_L, and V_F or aV_R, aV_L, and aV_F) and unipolar precordial leads are taken routinely by most physicians today.

The standard leads and the unipolar limb leads are related by the following equations:

By Definition

(1) Lead I $= V_L - V_R$
(2) Lead II $= V_F - V_R$
(3) Lead III $= V_F - V_L$

Then

$$(1) + (3) = \text{Lead I} + \text{Lead III} = V_L - V_R + V_F - V_L$$
$$= V_F - V_R = \text{Lead II}$$

This simple proof of Einthoven's law, which states that at any instant Lead II = Lead I + Lead III, indicates that the law is rigorously true because of the manner in which the limb leads are taken and that it does not depend on assumptions of any kind.

If equations (1) and (2) are added—

$$(1) + (2) = \text{Lead I} + \text{Lead II} = V_L - V_R + V_F - V_R$$

or $$(4) = \text{Lead I} + \text{Lead II} = -2V_R + V_L + V_F$$

Using the central terminal resistance network referred to below, it can be shown that Leads $V_R + V_L + V_F = 0$ or

Leads $V_L + V_F = -$ Lead V_R substituting the latter in equation (4)

$$-3V_R = \text{Lead I} + \text{Lead II}$$

$$\text{or } V_R = -\frac{I + III}{3}$$

Similar operations involving equations (1) and (3) and (2) and (3) give

$$V_L = \frac{I - III}{3} \text{ and } V_F = \frac{II + III}{3}$$

It should be pointed out here that the above equations are strictly true for leads V_R, V_L, and V_F, as they are measured by the central terminal arrangement, but do not give the true potentials of the three extremities V_R, V_L, and V_F, unless the assumptions, on which the Einthoven triangle is based, are valid.

These expressions for the unipolar extremity leads in terms of the three standard leads were first derived by Wilson, MacLeod, and Barker.[8] In 1931 and in 1934 the use of a resistance network, the central terminal, to establish an indifferent electrode with small potential variation throughout the heart cycle was described by Wilson, Johnston, MacLeod, and Barker.[9] Wilson fully appreciated that the central terminal could not have a zero potential because of the inaccuracies in the Einthoven triangle hypothesis upon which it is based. Nevertheless, without the central terminal unipolar leads of any kind would have been impossible.

Fig. 2a shows the circuit used to take unipolar extremity leads and 2b the modification of the circuit needed to obtain augmented leads (aV_R, aV_L, aV_F. The augmented leads were first suggested by Goldberger[10] and are usually employed because they are fifty per cent larger than the regular leads (V_R, V_L, V_F) and may be somewhat easier to interpret for this reason. It has been pointed out by several workers that the resistances in the central terminal should be at least 5000 ohms if the network is to function properly.

In 1941 Wilson, Johnston, Cotrim, and Rosenbaum[11] pointed out similarities in form between the unipolar leads, especially V_L and V_F, and precordial leads taken over the right and left ventricles. This paper made it clear that the mean electrical axis of QRS in the limb leads is determined to a large extent by the electrical position of the heart and explained why right and left axis deviation may not be found in tracings taken on patients with right and left ventricular hypertrophy, respectively.

Precordial leads were first taken in the late twenties, but it was not until 1938 that attempts to standardize technics for their registration began to bear fruit. Several important matters had to be considered, including the number of leads to be recorded, the positions on the precordium to be used and the indifferent electrode to be employed. Within recent years particularly, gradual agreement on these questions has been reached, and most physicians now take six precordial leads from the sites recommended by a special committee of the American Heart Association,[12] and the central terminal, rather than the left leg or some other point on the body, is used as the indifferent electrode.

Precordial leads supplement data supplied by the limb leads and are particularly valuable in the diagnosis of anterior myocardial infarction, bundle branch block, and ventricular hypertrophy, as will be pointed out later. Wilson and associates[13] have presented a detailed discussion of the precordial electrocardiogram.

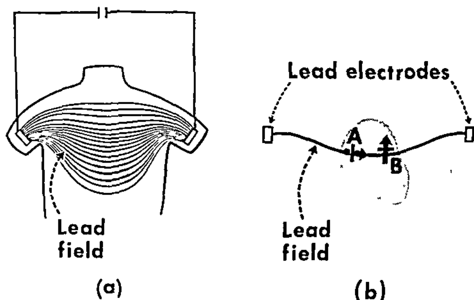


FIGURE 3 (a) The lead field of Lead I (b) The effect of two voltages within the heart on the lead field is illustrated. At (A) the maximum potential difference is produced in Lead I, while at (B) no potential is recorded so long as the voltage at B is perpendicular to the lead field

Although the Einthoven triangle concept helps greatly in an understanding of the behavior of the limb leads, until recently there has been no method to help in evaluating the characteristics of leads of other kinds. Lepeschkin[14] was probably the first to suggest a new principle for the study of leads in his "tubes of influence" and the lead vector of Burger and vanMilaan[15] was a further important step in the same direction. Unfortunately, the mathematical and rather abstract nature of the lead vector makes it difficult to understand and use. The closely related but simpler lead field described by McFee and Johnston[16] not only can be used to study the behavior of leads of all kinds but helps greatly in the design of new leads which should be superior to many in common use.

The lead field is defined as the current field that would exist in the body, including the heart, if a battery, of proper size to introduce unit current into the body, is connected to the electrodes of any lead. Thus, if such a battery is connected to electrodes on the two arms, the lead field would be much as shown in Fig. 3a. It will be observed that currents flow in a nearly transverse direction through the base of the heart but have considerable curvature near the apex.

The reader may very properly ask how the lead field is related to e.m.f.'s produced within the heart that cause electrocardiographic voltages to appear between electrodes placed on the surface of the body. The relation-

ship is very close, since it can be shown that e m.f.'s oriented in the direction of the lead field produce a maximal potential difference at the electrodes of the lead, while e.m.f.'s oriented at right angles to the lead field produce no voltage between the electrodes. Thus, in Fig. 3b an e.m.f. at A in the heart will contribute in the greatest possible degree to the lead voltage, while the same e.m.f. at B will have no effect on this voltage.

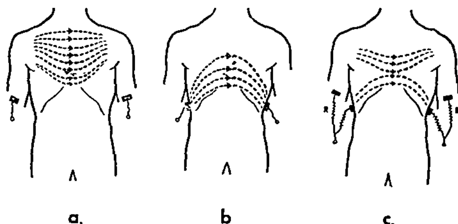


FIGURE 4 Correcting the curvature of the field of Lead I (a) Usual Lead I (b) Corrective lead. (c) Lead I, corrected

The nature of the lead field in the heart shows at a glance how sensitive the lead will be to cardiac e.m.f.'s oriented in different directions, and one of the big advantages of the lead field is that its general pattern in the heart is easily determined by simple sketch for any type of lead or lead system.

As an illustration of the usefulness of the lead field idea let us refer again to Fig. 3a The character of the field for Lead I tells us that voltages arising near the base of the heart will be well recorded in this lead *provided these voltages are oriented transversely* but that this is not strictly true of transverse e.m.f.'s located near the apex. In other words, Lead I is only a fairly good lead for the registration of the transverse or horizontal components of cardiac e m.f.'s. Its performance in this respect would be improved if the curvature of the lead field through the apex could be eliminated. This can be largely accomplished, as has been pointed out by McFee and Johnston,[16] by combining ordinary Lead I with another lead using electrodes on the right and left lateral aspects of the thorax slightly below the level of the heart. The lead field of this second lead would have curvature opposite to that of Lead I in the apical region of the heart, and their combination should yield a field of the desired type. This corrected Lead I is illustrated in Fig. 4.

The above discussion should make the value of the lead field concept clear. The same principles outlined in connection with analysis (and correction) of Lead I may be used to obtain satisfactory leading systems for the vertical and sagittal components of the cardiac e.m.f.'s. Such leads are important in vectorcardiography, as will be pointed out below.

Wilson and Johnston[17] in 1938 described a method for combining two ordinary electrocardiograms, using a cathode-ray oscillograph to produce figures which represent the P waves, QRS complexes, and T waves as a series of loops (see Fig. 5). These figures are much like the monocardiograms obtained from proper combination of the limb leads by Mann[18] in

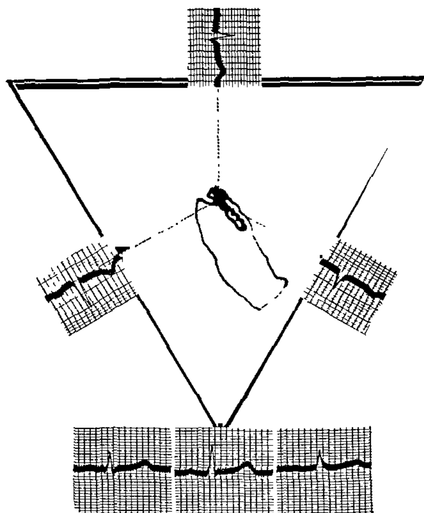


FIGURE 5 Vectorcardiogram of a normal subject taken by the method described in the text The large loop corresponds to the Q-R-S group, the small inside loop corresponds to the T wave The standard limb leads are reproduced below the triangle and are also shown at the sides of the triangle in their proper orientation

1919. Wilson suggested the term vectorcardiogram for these records, and vectorcardiography has been a field of great interest in recent years.

It is important to keep in mind that, since vectorcardiograms must always be derived from the more or less precise combination of two conventional electrocardiograms, these figures are only a different method for the display of ordinary electrocardiographic data and not a radically new technic for investigation of e.m.f.'s arising in the heart. Vector-

cardiograms are more obviously related to electrical events existing in the heart than are ordinary tracings, and phase differences not easily discovered by inspection of conventional electrocardiograms are made clear in the vector figures.

The vectorcardiogram illustrated in Fig. 5 was obtained by the combination of a transverse component (Lead I) and a vertical component ($\sqrt{3}\ V_F$) of the cardiac e m f.'s on the cathode-ray oscillograph and is

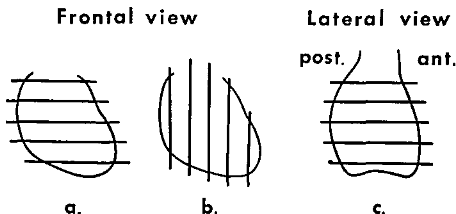


FIGURE 6 The ideal lead fields for the horizontal, vertical, and sagittal components

therefore in the frontal plane. If a transverse component is combined with a sagittal component or a vertical component is combined with a sagittal component, vectorcardiograms in the horizontal and sagittal planes respectively will be obtained. If vectorcardiograms in two of the three planes are available, the spatial orientation of the figures can be derived, and a great deal of work in spatial vectorcardiography has been done in recent years Duchosal and Sulzer[19] pioneered in this field, and in this country Burch and associates,[20] Grishman and Sherlis,[21] and others have carried out extensive work of this kind All of these workers have used the cathode-ray oscillograph for the registration of the vector figures and all, except Burch and associates who have used the equilateral tetrahedron, have employed, in more or less modified form, the so-called cube system first described by Duchosal and Sulzer to obtain the necessary transverse, vertical, and sagittal components of the cardiac e.m f.'s.

As was implied in the discussion of the lead field earlier in this chapter, the ideal lead fields for the transverse, vertical, and sagittal components for vectorcardiography should be like those shown in Fig. 6a, b, and c, and, therefore, the best leads for vectorcardiography should have lead fields of these types. Analysis of the fields associated with all leads commonly used in vectorcardiography indicates that V_F (or aV_F) is a good one for the vertical component, Lead I is only fairly good (see lead field discussion above) for the horizontal component, and that all other leads are poor. This can only mean that a great many vectorcardiograms that have been taken in recent years, particularly those obtained with the cube system, are open to serious criticism relative to their accuracy.

A large literature on spatial vectorcardiography has already accumulated, and readers interested in more details about technical and other aspects of this special corner of electrocardiography are referred to the many articles on this subject. For reasons outlined above, the authors do not share a great deal of the enthusiasm evinced by many workers concerning the diagnostic value of vector records. If technics for the accurate demonstration of the vector figures in space like those described by Schmitt and Levine[22] can be simplified, vectorcardiography may have important and widespread clinical use.



FIGURE 7 Lead I (above) and an esophageal lead (below) in a case of partial heart block. In the esophageal lead the auricular deflections (P) are very large and display a conspicuous intrinsic deflecti
The esophageal electrode was attached to
lead wire was attached to an indifferent
phageal electrode was 40 cm. from the teet
the galvanometer at one-half the norm
Medicine, F A Davis Co)

Esophageal and other special leads, such as intracardiac leads, have had only limited use. The former might be expected to help in the diagnosis of posterior myocardial infarction, but for several reasons have not proved to be of great value in this condition. The greatest value of esophageal leads is in connection with the cardiac arrhythmias, where other leads fail to make the mechanism, particularly that of the auricles, clear. Fig. 7 illustrates an esophageal lead taken in a patient with A-V heart block.

INTRAVENTRICULAR BLOCK

All of the ventricular muscle passes into the excited state during the inscription of the initial deflections of the ventricular complex. When the excitation process reaches the ventricles by the normal route, the length of the QRS interval may, therefore, be regarded as a measure of the efficiency of the intraventricular conducting system; an increase in this interval beyond the upper normal limit of 0.10 sec. must be ascribed to a defect in conduction below the bifurcation of the His bundle. It is obvious that at points where the path of the excitation wave is narrow, it may be obstructed by a small area of impaired conductivity; where the path is wide, it is much less easily blocked. For this reason, a small lesion which involves one of the main branches of the His bundle may produce a conspicuous increase in the QRS interval and a profound change in the form of the ventricular complex, while lesions which involve the Purkinje network must be extensive if they are to give rise to alterations of a similar

grade. Toxic influences, unlike discrete structural lesions, may depress the conductivity of the ventricular conducting system as a whole. There is at the present time no evidence that lesions which involve only the ordinary ventricular muscle can give rise to a measurable increase in the duration of the initial deflections. Ventricular hypertrophy, by increasing the thickness of the ventricular walls, and therefore the length of the path through ordinary ventricular muscle which the excitation process must pursue, undoubtedly increases the length of the QRS interval; but the evi-

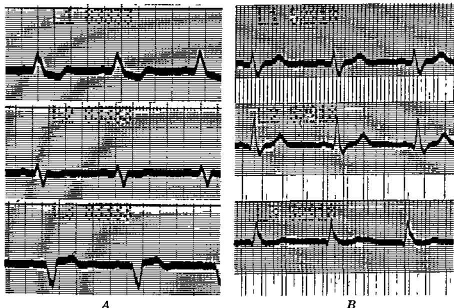


FIGURE 8 *A*, Limb leads in complete left bundle branch block *B*, Complete right bundle branch block

dence bearing upon this problem seems to indicate that an increase in this interval beyond 0.10 sec. is seldom due to this cause. In the Wolff-Parkinson-White syndrome, the QRS interval is abnormally long and the P-R interval abnormally short because of the premature activation of some part of the ventricular muscle by an auricular impulse which reaches it by some pathway other than the His bundle.

The broad term *intraventricular block* is applied to all those conditions in which a defect in intraventricular conduction is suspected because the QRS interval exceeds 0.10 sec. According to the location of the conduction defect, when this can be ascertained, several varieties of intraventricular block may be distinguished. When the conduction defect completely interrupts the passage of the cardiac impulse through one of the two main branches of His bundle, the QRS interval ordinarily measures 0.12 sec. or more, and the form of the ventricular deflections is usually sufficiently distinctive to permit a diagnosis of *complete bundle branch block*, right or left as the case may be, to be made with confidence.

Incomplete bundle branch block, due to conduction defects that merely retard the passage of the impulse through one of the main bundle branches,

gives rise to electrocardiograms which are of less distinctive character and are transitional, both as regards the length of the QRS interval and the form of the ventricular deflections, between those which represent complete bundle branch block and electrocardiograms of normal outline.

Fig. 8 shows the limb leads taken from patients with complete right and left bundle branch block. In right branch block, both complete and incom-

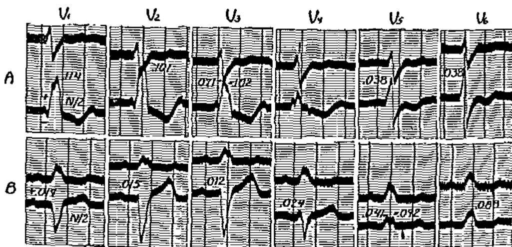


FIGURE 9 *A*, Serial precordial leads taken simultaneously with Lead I (above) in a case of right bundle branch block The decimal figures give the time of the chief downstroke (intrinsic deflection) with reference to the onset of the earliest ventricular deflection in Lead I Where two conspicuous downstrokes are present, the time of each is indicated. The surface of the right ventricle was activated about 0.06 second later than the surface of the left. *B*, Serial precordial leads in a case of left bundle branch block The surface of the right ventricle was activated about 0 07 second earlier than the surface of the left. The time intervals are fifths of a second. In the case of the precordial leads, the ordinate scale is 2 mv per cm. (N/2) The precordial electrode was attached to the left-hand lead wire and paired with a central terminal (Cyclopedia of Medicine, F. A Davis Co)

plete, a broad S wave is likely to be seen in Lead I, and in left branch block such a wave is usually absent. This is true because there are ordinarily similar findings in precordial tracings taken over the left ventricle (V_5 and V_6) and, with a horizontal or semi-horizontal heart, Lead I reflects these characteristics. If, as occasionally happens, the heart has a vertical or semi-vertical position, Lead I may no longer show an S wave in the presence of right branch block, and an S wave in this lead may appear with left branch block. This means that the limb leads cannot always be relied upon to make the decision whether right or left branch block is present, and findings in precordial leads must be used.

Fig. 9 shows precordial leads that illustrate complete right and left branch block. In the former a late secondary R wave, due to delayed excitation of the right ventricle, is seen in leads taken over that chamber (V_1 thru V_3), and in the latter a broad R wave with a late peak due to late activation of the left ventricle is present in V_5 and V_6, recorded over that chamber. These are the basic electrocardiographic signs of right and

left branch block amply confirmed by experimental studies and much other clinical evidence.

Examples of incomplete right and left branch block are shown in Fig. 10. They are similar in general outline to the tracings that show complete bundle branch block except that the QRS intervals are shorter in the former and R waves are often larger and show less notching in chest leads V_5 and V_6 in incomplete left branch block.

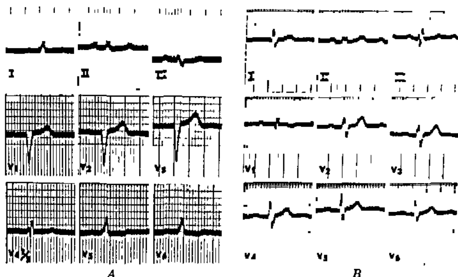


FIGURE 10 Limb and precordial leads taken in *A*, incomplete left bundle branch block, and in *B*, incomplete right bundle branch block

One perplexing problem is the large number of tracings, often recorded on presumably normal subjects, that show late secondary R waves in either chest lead V_1 or V_2, or both The QRS interval is frequently within normal limits (0.07-0.10 sec.), and the late R waves are often small and narrow. The question that arises, of course, do these tracings represent true incomplete right branch block and, if so, should they be considered to indicate some cardiac abnormality? The writers suspect that many of these records, particularly the ones with the shorter QRS intervals, show late secondary R waves as a result of physiologic late activation of the base of the right ventricle and not from incomplete right branch block. In any event, a very conservative attitude should be followed in the interpretation of these tracings. This is particularly important because it is not rare to find definite (even complete) right branch block, and occasionally left branch block, in individuals who have no other findings pointing to heart disease.

VENTRICULAR HYPERTROPHY

In previous editions of this book considerable space in this section was devoted to a discussion of axis deviation and some of the reasons why right and left axis deviation do not always point to selective hypertrophy of the right and left ventricles, respectively. Most of this material is unnecessary in view of the fact that, although the mean electrical axis of QRS deviates

to the left with left ventricular and to the right with right ventricular hypertrophy, its direction is even more dependent on the electrical position of the heart, as was mentioned in the discussion of electrocardiographic leads earlier in this section. Like so many other basic concepts in electrocardiography, we owe this one to the genius of Wilson,[11] and it allows us to understand why many patients with left ventricular hypertrophy have

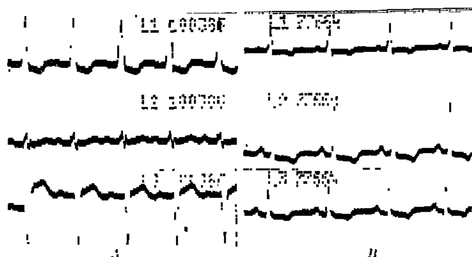


FIGURE 11 *A*, An example of left ventricular hypertrophy in the horizontal position showing left axis deviation with inverted T waves in lead I *B*, Left ventricular hypertrophy in the semi-vertical position showing normal axis deviation with increased voltage of the R-wave and negative T-waves in all leads

electrocardiograms that do not show left axis deviation and may even show right axis deviation Less commonly, patients with right ventricular hypertrophy do not have right axis deviation in their electrocardiograms, and rarely is left axis deviation seen. The above makes it clear that axis deviation is not a reliable guide for the diagnosis of hypertrophy. As Wilson stated in 1941, "the exact position of the mean electrical axis of the heart is of no clinical importance."

Fig. 11 shows the limb leads taken from two patients with left ventricular hypertrophy. Left axis deviation is seen in Fig. 11A, where the heart has a transverse or horizontal electrical position, but is absent in Fig. 11B because the heart has a semivertical position.

Fig. 12 shows precordial electrocardiograms from patients with right and left ventricular hypertrophy. In cases of preponderant enlargement of the right ventricle, precordial leads from the right side of the precordium (Leads V_1 and V_2) usually display an abnormally large preintrinsic upward deflection (R) and an abnormally late intrinsic deflection. Very often the intrinsic deflection is later in these leads than in leads from the left side of the precordium. In the latter, the ventricular complex does not, as a rule, display striking abnormalities In preponderant enlargement of the left ventricle, precordial leads yield ventricular complexes similar in general outline to those obtained in normal subjects. The chief differences consist in an exaggeration of the size of the postintrinsic downward deflection (S) in leads from the right side of the precordium, of the

size of the preintrinsic upward deflection (R) and sometimes of the initial downward deflection (Q) in leads from the left side of the precordium, and of the interval which normally separates the onset of the intrinsic deflection in the former curves and its onset in the latter.

With marked right ventricular hypertrophy, a reversal of the usual pattern (*i. e.*, QRS complexes of the type commonly found over the left ventricle appear in V_1 and V_2 and complexes like those usually present over

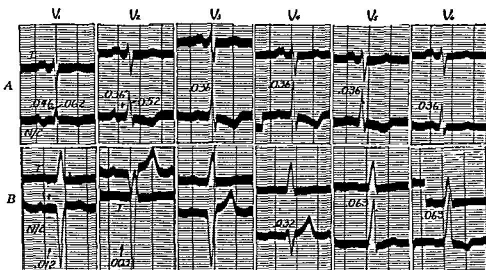


FIGURE 12. *A*, Serial precordial leads in a case of preponderant hypertrophy and enlargement of the right ventricle (mitral stenosis) The intrinsic deflection is later in the leads from the right side of the precordium (V_1 and V_2) than in the leads from the left side *B*, Serial precordial leads in a case of preponderant hypertrophy and enlargement of the left ventricle (syphilitic aortic regurgitation). The intrinsic deflection is abnormally late in the leads from the left side of the precordium (V_5 and V_6). The ordinate scale for these leads is 2 mv per cm. (N/2). The clinical diagnosis and the type of preponderant hypertrophy specified was confirmed at necropsy in each instance (Cyclopedia of Medicine, F. A Davis Co)

the right ventricle occur in V_5 and V_6) is not uncommon, and with slight hypertrophy of this chamber little change from the normal configuration, except for small QRS complexes with somewhat late R waves in V_1 and V_2, is seen. In adults, precordial tracings are quite reliable for the diagnosis of right ventricular hypertrophy, but in infants and young children the uncertainties are greater. This is true because there is physiologic right ventricular preponderance in these patients, and it is often difficult to be sure whether abnormal increase in thickness of this chamber is present. Studies on normal infants and children by Ziegler[7] and others have helped to clarify this problem.

Since the changes in precordial leads with left ventricular hypertrophy are quantitative rather than qualitative (as they are with right ventricular hypertrophy), it is frequently hard to be sure whether records showing large S waves in V_1 through V_3 and quite large, fairly late R waves in V_5 and V_6 mean left ventricular hypertrophy or not. In attempts to over-

come this difficulty several workers have developed rule of thumb methods which they believe may help. Thus, Sokolow and associates[23] have suggested that if the sum of the S wave in V_1 and the R wave in V_5 is more than 3.5 millivolts, left ventricular hypertrophy is likely. Myers and associates[24] believe that late R waves in V_5 and V_6 are the best indicators of left ventricular hypertrophy, and the authors agree, especially if the R waves are large and if incomplete left branch block can be excluded. None of these guides is entirely satisfactory, and there are no criteria that can be used without some reservations.

Cabrera and associates[25] in Mexico City have pointed out that more or less characteristic electrocardiographic signs are related to the type of physiologic disturbance in the ventricles. Thus, with diastolic overloading of the right ventricle, as occurs commonly with interauricular septal defects, right bundle branch block is a very frequent finding, while with systolic overloading (pulmonic stenosis) the changes expected with right ventricular hypertrophy appear. This work is of considerable interest, although one must always be careful in attempting to correlate electrical with mechanical events in the heart.

In this connection a few remarks are in order about the term strain, so often used by some in electrocardiographic interpretation. The writers do not know who has the doubtful honor of introducing this very inappropriate word to describe an electrical record, but it has been used so long and so widely that little can be done to eliminate it from electrocardiographic parlance now.

ABNORMALLY LARGE OR SMALL Q-R-S DEFLECTIONS; NOTCHING OF Q-R-S

Very large QRS deflections, measuring well over two millivolts (2 cm.) in the limb leads and four millivolts or more in precordial leads, are most commonly seen in the electrocardiograms of young individuals with very large hearts and good or fairly good cardiac function, particularly in cases of congenital heart disease and of rheumatic aortic insufficiency. In hypertension associated with great cardiac enlargement they are encountered somewhat less frequently. The QRS deflections of the standard leads are considered abnormally small when the largest deflection in any lead measures less than 0.5 millivolt (5 mm.). Small deflections of normal out line may occur in normal subjects, and too much stress should not be placed upon such deflections when there is no other abnormality of the ventricular complex. Very small deflections of bizarre outline are commonly seen in patients with high grade cardiac failure associated with edema. The deflections sometimes, although not always, get larger as the cardiac function improves and the edema disappears. Small deflections are also frequently encountered in myxedema and in myocardial infarction; less often in a variety of other conditions.

Marked splintering or notching of QRS in Lead III when the deflections in this lead are small is in no way abnormal. A similar splintering or notching of QRS does not occur normally in Lead I nor in Lead II. Slight notching or slurring of QRS in these leads is, however, common enough.

In normal precordial electrocardiograms notching is not rare and appears to be due to the time interval which separates activation of the surface of the thin right ventricular wall and activation of the surface of the thick left ventricular wall. Deep notching of the chief QRS deflection near its apex in leads of large amplitude suggests the presence of intraventricular block. It is frequently associated with a slight increase in the QRS interval. Initial deflections which resemble the letter M or the letter W in outline and are of small size have no significance when present in Lead III only; when present in Lead I or Lead II, they suggest intraventricular block or myocardial infarction In general, however, *great caution should be exercised in the interpretation of notching, slurring, or other minor abnormalities of the QRS deflections.*

Langner[26] has taken conventional electrocardiograms with equipment having far better high frequency response than ordinary electrocardiographs and has found notching and slurring in these tracings not clearly seen in usual records. It remains to be determined whether these findings will be of clinical importance.

THE T DEFLECTION AND THE VENTRICULAR GRADIENT

The T wave is due to repolarization of the ventricular muscle, and it differs from depolarization in several important respects. It takes place much less rapidly than depolarization, it occurs more quickly in some parts of the ventricle than in others, and this recovery process is easily modified by many things which would not influence depolarization. This means that the T waves are much more easily altered in size or direction than are the QRS complexes. Slight differences in temperature, arterial circulation, rate of removal of metabolic waste products, and other things may alter repolarization and cause definite alterations in the T waves. The ease with which these waves are changed should be kept in mind by the physician who interprets electrocardiograms. This is particularly true, since some things, such as hyperventilation and large meals, which have nothing to do with heart disease may cause transient T wave "abnormalities" to appear. The physician who does not recognize this lability of the T waves and assumes that T wave abnormalities are always due to myocardial disease (often coronary sclerosis!) is a menace to his patients.

In normal adults, the T waves are usually upright in Leads I and II and in most of the precordial leads Inverted T waves are a common normal finding in Lead III, in chest leads V_1 and V_2 and occasionally in V_3.

If the development and decline of the excitatory process were the same in all parts of the ventricular muscle, so that the duration of systole were everywhere uniform, the different parts of the ventricular muscle would pass through the activation and the deactivation process in the same order, and the area of QRS and the area of T in the same lead would necessarily be equal in magnitude but opposite in sign. The sum of these areas, the area of QRST, would then be zero in all leads. The area of QRST in a given lead may, therefore, be considered a measure of the mean potential difference produced in that lead by variations in the length of systole in the different units of ventricular muscle; variations

brought about by local causes. The area of QRST in a given lead is equal to the area of the T deflection which would have been inscribed in that lead if all the ventricular muscle had passed into the active state at the same instant, or if the area of QRS were zero. The mean electrical axis of T gives the direction and magnitude of the electrical forces produced by ventricular deactivation, and the mean electrical axis of QRST, the magnitude and direction of the electrical forces produced by local variations in the excitatory process. The mean electrical axis of QRST may be referred to as the *ventricular gradient.*

One difficulty in the solution of problems involving the significance of abnormal T deflections arises from the circumstance that the form of T is to a considerable extent dependent upon the contour of the initial ventricular deflections. It is determined by the order in which the ventricular muscle passes out of the excited state, and this in turn depends upon at least two independent factors: (1) Upon the order of activation, which controls the form of the QRS deflections; and (2) upon the presence of variations, normal or abnormal, in the duration of systole in different muscle units. Such variations are due to local causes. It is desirable to be able to distinguish between secondary abnormalities of T due to the first factor and primary abnormalities due to the second. Abnormalities of the first kind have no significance other than that which may be ascribed to the abnormalities of the QRS deflections upon which they directly depend

It has been pointed out above that the area of QRST in a given lead is equal to the area of the T deflection which would have been inscribed if the area of QRS were zero. By measuring the area of QRST it may, therefore, be determined whether the form of QRS is solely responsible for inversion of T in a given instance, or whether the latter is dependent upon abnormal local variations in the excitatory process. The diphasic character of the ventricular complexes commonly seen in bundle branch block and in many cases of axis deviation is directly due to the large area of QRS which controls the direction of the T deflection. Ventricular complexes of the normal type are polyphasic because the area of QRS is too small to overbalance the effects produced by local variations in the excitatory process. When these local variations are very great, they may determine the direction of T even though QRS has a large area

Wilson and associates[27] recognized the existence of a spatial gradient, and Ashman, Gardberg, and Byer[28] estimated its characteristics roughly. More recently, Simonson and associates[29] with more refined technics have studied the gradient both in the frontal plane and in space. They believe that the frontal plane projection of the gradient varies so greatly in normal subjects that it is of little value in differentiating between primary and secondary T wave changes in the limb leads but that the normal spatial gradient may be less variable and repay further study.

MYOCARDIAL INFARCTION

In the diagnosis of recent myocardial infarction, the electrocardiogram is of the greatest importance. It frequently yields data which point

unequivocally to the presence of infarction when physical and x-ray examinations disclose no definite cardiac abnormality. *Because the changes in the electrocardiogram are progressive and the sequence of changes is characteristic, it is important to obtain a series of curves whenever it is possible.*

The earliest change usually consists in a temporary displacement of the RS-T junction and the portion of the ventricular complex which immediately follows it (RS-T segment). Slight permanent displacement (1-2 mm.) of this junction and segment is sometimes seen in normal subjects, and more pronounced permanent displacement is common in bundle branch block and in axis deviation

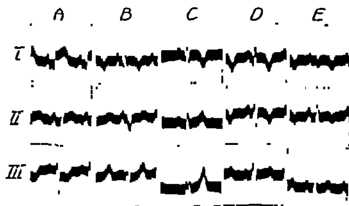


FIGURE 13 Series of electrocardiograms which display changes in the ventricular complex of the kind produced by infarction of the anterior ventricular wall In Lead I the QRS deflections are small and a conspicuous Q deflection is present In *A* there is pronounced displacement of the RS-T junction and segment. In *B*, *C*, *D*, and *E*, sharply inverted "coronary" T waves occur in Lead I or in Leads I and II (Cyclopedia of Medicine, F A Davis Co)

Apart from the displacement of the RS-T segment without much change in the position of the RS-T junction commonly seen after the administration of digitalis, temporary RS-T displacement is almost always due either to very recent coronary occlusion or to acute pericarditis. In the former, the displacement in Lead I is usually opposite in direction to the displacement in Lead III, while in the latter the direction of the displacement is usually the same in all three leads.

The RS-T displacement of coronary occlusion rapidly diminishes in most cases and ordinarily lasts only a few hours or a few days. As it declines, characteristic T wave changes almost invariably develop. The decline of upward RS-T displacement is accompanied by sharp inversion of the end of the T wave; as the inversion becomes more pronounced, it progresses backwards towards the QRS group. The final result is a very large, sharply inverted, V-shaped T deflection with a shoulder on its descending limb, which is convex towards the base line. These peculiar T waves have been referred to as "cove plane T waves" and as "coronary T waves." Their appearance is most distinctive during the period when

some displacement of the RS-T junction is still present. Downward RS-T displacement is followed by T wave changes of the same kind, except that the direction of T is reversed so that it becomes a sharp-peaked, upward deflection. The T wave changes ordinarily reach their maximal development in two or three weeks, and persist for several months. In the course of time, inverted "coronary T waves" are replaced by upright T waves, or gradually lose their distinctive outline.

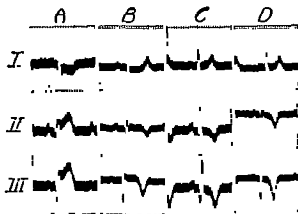


FIGURE 14 Series of electrocardiograms of the kind seen in cases of infarction of the posterior ventricular wall Conspicuous Q deflections are present in Leads II and III. In *A* there is pronounced displacement of the RS-T junction and segment, while in *B*, *C*, and *D*, inverted "coronary" T waves are present in Leads II and III (Cyclopedia of Medicine, F. A. Davis Co)

The kind of changes which develop in the different limb leads depend upon the location of the infarcted region. When the infarct lies on the anterior wall and involves the left margin of the heart, upward RS-T displacement and inversion of T occur in Lead I and aV_L with changes of the opposite type in Lead III. These changes in the final deflections of the ventricular complex are very often accompanied by alterations in the QRS deflections (Fig. 13). In Lead I these deflections become small, and the most characteristic configuration is a prominent and sometimes broad Q wave followed by an R wave 5 mm. or less in height. In Lead III, Q is not present; R may be the only deflection of the QRS group in this lead, but very often it is followed by a large S. The ventricular deflections of Lead II usually resemble those of Lead III, but may resemble those of Lead I.

When the infarct involves the posterior wall and diaphragmatic margin of the heart, prominent Q waves appear in Leads II, III, and aV_F, and these are the leads in which upward RS-T displacement and inversion of T occur (Fig. 14). In Lead I, Q is usually absent or very small, the R-S-T displacement is downward, and the altered T waves are upright.

Unlike the changes in the T wave, those which occur in the QRS group are, as a rule, permanent and often make it possible to render a tentative diagnosis of old myocardial infarction in cases in which the coronary accident occurred several years before the electrocardiographic

examination. The most characteristic QRS changes in anterior infarction consist in a mean electrical axis which is nearly vertical, a Q wave in Lead I measuring at least 1 mm. and at least one-fifth as large as the largest R in any lead, and an R wave in Lead I measuring 5 mm. or less in height. The most characteristic changes in posterior infarction consist

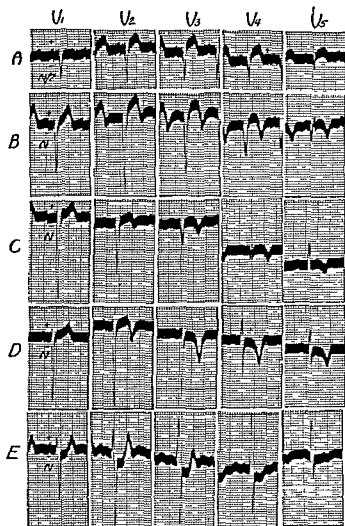


FIGURE 15. Serial precordial electrocardiograms obtained in five cases of coronary occlusion. In *A*, *B*, *C*, and *D*, the changes in the ventricular complex point to infarction of the anterior ventricular wall. In the first (*A*), an abnormally large initial downward deflection is followed by upward displacement of the RS-T junction and segment. In *B*, a later stage of infarction is represented; upward displacement of the RS-T segment is giving place to sharp inversion of the T deflection. In *C* and *D*, the "coronary" T waves are well-developed, in the former, the QRS changes are characteristic, in the latter they are absent or questionable. In *E*, there is downward displacement of the RS-T junction and segment, pointing to very recent infarction of the posterior ventricular wall, but the QRS deflections are not abnormal. In *A*, the ordinate scale is 2 mv. per cm. (N/2). In *B*, *C*, *D*, and *E*, the ordinate scale is 1 mv. per cm. (N). (Cyclopedia of Medicine, F. A. Davis Co.)

in a Q wave in Lead III at least one-half as large as the largest QRS deflection in any lead, a Q wave in Lead II measuring at least 1 mm. and at least one-fourth as large as R in Lead II, and a mean electrical axis which is shifted to the left or is in the normal position. Large Q waves in Lead III only are common in patients who give a history which suggests coronary occlusion or who complain of anginal pain, but since they sometimes occur in pregnant women in association with elevation of the diaphragm, and in normal subjects who are obese, they are of comparatively little help in diagnosis. A positive diagnosis of coronary occlusion should not be based upon the electrocardiogram alone unless unequivocal changes of characteristic type are present in both the initial and the final deflections.

When the anterior wall of the heart is infarcted, characteristic changes are present in the precordial electrocardiogram in many instances in which they are absent in the standard three-lead electrocardiogram. They consist in the sequential development of pronounced upward displacement of the RS-T junction and segment, of an abnormal large initial downward deflection (Q) which is often the sole deflection of the QRS group, and of very large inverted T deflections of the "coronary" type (Fig. 15). These characteristics are often most conspicuous when the precordial electrode is placed directly over the apex beat (Lead V_4), but in some instances they are more pronounced in leads in which this electrode is placed near the left sternal border or halfway between this border and the apex beat (Leads V_2 and V_3). When QRS changes are present alone, they should not be considered of diagnostic importance unless they occur in leads in which the exploring electrode is placed to the left of a point midway between the left sternal margin and the midclavicular line.

When the posterior wall of the heart in infarcted, precordial leads are rarely helpful except during the period when RS-T displacement is present. During this period they usually show conspicuous RS-T displacement in the downward direction.

In some cases, myocardial infarction leads to temporary or permanent disturbances of intraventricular conduction (intraventricular block, bundle branch block) which tend to obscure the characteristic changes described in preceding paragraphs. In other cases, the chief features of the ventricular complexes of the standard leads are the small size and bizarre outline of the QRS deflections. Atrioventricular block, paroxysmal ventricular tachycardia, auricular fibrillation, and other disturbances of rhythm frequently occur.

Additional chest leads taken at a higher level than usual may show changes characteristic of myocardial infarction in patients with high anterolateral infarcts when the usual precordial leads do not, and Elek and associates[30] have suggested the use of leads from the left posterior chest for the recognition of strictly posterior infarcts.

Subendocardial infarction may not produce any of the characteristic electrocardiographic findings mentioned above and depression of RS-T segment in all standard leads and in chest leads V_5 and V_6 may be the only changes produced by this type of infarct. Wood and associates[31]

described electrocardiographic evidence of this kind with what they thought was lateral infarction many years ago, and Pruitt and associates[32] have shown that subendocardial infarcts may cause only terminal inversion of the T waves in leads taken from the midprecordial area.

Experimental studies done by Durrer and vanderTweel,[33] Prinzmetal and associates,[34] and Sodi-Pallares and associates[35] suggest that passage

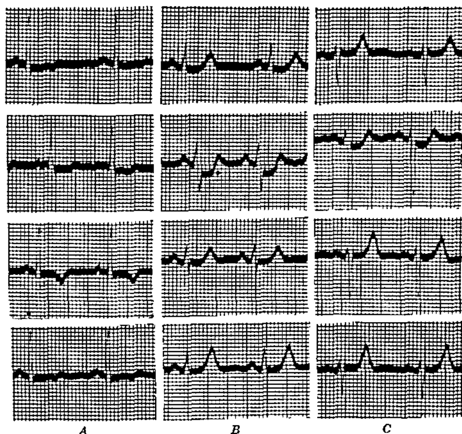


FIGURE 16 *A*, Control electrocardiogram *B*, During spontaneous angina pectoris. *C*, Five minutes later after nitroglycerin 0 6 mg (1/100 grain) *D*, Ten minutes after C. The patient, a physician, age sixty-six, with mild hypertension and angina pectoris, died suddenly one week after these observations (Reprinted from Trans. Am. Assoc. Phys 54 210)

of the activation wave through the wall of the ventricle is not the purely radial type of spread previously assumed Similar work done by Scher and associates,[36] however, is interpreted to support the early concept of basically radial spread of the activation wave. This matter is of the greatest importance, not only in connection with infarction, but with many other conditions, and further studies are clearly needed.

ANGINA PECTORIS

Although many patients with typical angina pectoris have normal electrocardiograms, especially if the records are taken between attacks, the presence of intraventricular block or T wave abnormalities may help in the

diagnosis. It was discovered many years ago that transient depression of the RS-T segment often followed by T wave inversion, then a prompt return to normal, occurs during and for a short time after an anginal seizure. Accompanying these RS-T segment and T wave changes, S waves not previously present (or deeper than those initially seen) frequently develop. These alterations occur in the standard leads but usually are more definite in chest leads taken over the left ventricle. Fig. 16 illustrates the nature of these abnormalities and their transient character.

These RS-T segment and T wave changes are presumably due to subendocardial ischemia, but the cause for the QRS changes is unknown. Since they appear very commonly with anginal attacks, it is clear that they may be of diagnostic value, and Master and associates[37] have written extensively on this subject. Some patients with angina have such atypical substernal discomfort that a diagnosis cannot be made from the history. In these patients and in those in whom for any reason a reliable history cannot be obtained an exercise test may be indicated.

The authors believe that all such tests should be supervised by physicians and not be done routinely by technicians. Furthermore, a control tracing should always be taken and be carefully examined shortly before the patient is subjected to the test, and finally, arbitrary rules relative to the amount of RS-T segment depression necessary to consider the test positive are unwise, in our opinion.

Many patients, either in the early phases of acute coronary occlusion or with increasing severe angina pectoris, have electrocardiographic findings like those seen during acute anginal attacks but are different because the RS-T segment abnormalities persist for relatively long periods of time. Tracings of this kind have been called examples of "coronary insufficiency" by Master and associates.[38] The authors consider this a very poor term, because all coronary disease, ranging from mild angina pectoris to severe myocardial infarction, are examples of coronary insufficiency, and especially because the phrase is a poor one to describe an electrocardiographic abnormality. It is probable that these changes are due to subendocardial ischemia resulting from marked narrowing or spasm of a coronary artery.

REFERENCES

1. Surawicz, B., and Lepeschkin, E.: Circulation 8:801, 1953
2. Kossmann, C. E.: Circulation 8:920, 1953.
3. Lown, B., Ganong, W. F., and Levine, S. A.: Circulation 5:693, 1952
4. Cheer, S. N., and Dieuaide, F. R.: J. Clin. Invest. 10:889 (Oct.) 1931.
5. Taran, L. M., and Szilagyi, N.: Am. Heart J. 33:14, 1947.
6. Pokress, M. J., and Goldberger, E.: Am. Heart J. 38:423, 1949
7. Ziegler, R. F.: Electrocardiographic Studies in Normal Infants and Children, C. C. Thomas, Springfield, Ill., 1951.
8. Wilson, F. N., MacLeod, A. G., and Barker, P. S.: Am. Heart J. 7:207, 1931.
9. Wilson, F. N., Johnston, F. D., MacLeod, A. G., and Barker, P. S.: Am. Heart J. 9:447, 1934
10. Goldberger, E.: Am. Heart J. 23:483, 1942
11. Wilson, F. N., Johnston, F. D., Cotrim, N., and Rosenbaum, F. F.: Trans. Ass'n of Am. Physicians 56:258, 1941.

12 Report of Committee of the Am Heart Ass'n on Standardization of Precordial Leads, Am. Heart J. 15:235, 1938
13 Wilson, F. N.; Johnston, F. D, Rosenbaum, F F; Erlanger, H, Kossmann, C E, Hecht, H; Cotrim, N.; Menezes de Oliveira, R; Scarsi, R.; and Barker, P S. Amer. Heart J 27:19, 1944
14 Lepeschkin, E.: Modern Electrocardiography, Williams and Wilkins, Baltimore, 1951.
15 Burger, H C., and vanMilaan, J. B.: Brit. Heart J 8:157, 1946—9 154, 1947—10:229, 1948
16 McFee, R., and Johnston, F. D. Circulation 8:554, 1953—9.255, 1954—9 868, 1954.
17. Wilson, F. N., and Johnston, F D: Am. Heart J 16:14, 1938
18 Mann, H., Arch. of Int. Med 25:283, 1920
19. Duchosal, P. W., and Sulzer, R: La Vectorcardiographie, S Karger, Basle, 1949.
20 Burch, G E, Abildskov, J. A., and Cronvich, J A: Spatial Vectorcardiography, Lea and Febiger, Philadelphia, 1953.
21 Grishman, A, and Sherlis, L.: Spatial Vectorcardiography, W B Saunders Co, Philadelphia, 1952
22 Schmitt, O. H, and Levine, R: Federation Proc 11.140, 1952
23. Sokolow, M, and Lyon, T. P.: Am. Heart J 37:161, 1949
24 Noth, P. H, Myers, G B, and Klein, H. A J Lab and Clin. Med. 32:1517, 1947
25 Cabrera, E, and Monroy, J R: Am. Heart J 43 661, 1952—43 669, 1952
26 Langner, P. H, Jr: Circulation 5 249, 1952
27. Wilson, F. N, MacLeod, A G, Barker, P. S, and Johnston, F D. Am. Heart J 10:46 (Oct) 1934.
28 Ashman, R, Gardberg, M, and Byer, E Am. Heart J. 26.473, 1943
29. Simonson, E., Schmitt, O H, Dahl, J, Fry, D, and Bakken, E E: Am. Heart J. 47:122, 1954
30. Elek, S. R, Herman, L M, and Griffith, G. C: Circulation 7 656, 1953
31. Wood, F. C., Wolferth, C C, and Bellet, S: Am. Heart J 16:387, 1938
32 Pruitt, R. D, Klakeg, C H, and Chapin, L. E: Circulation 11 517, 1955
33 Durrer, D, and vanderTweel, L. H. Am. Heart J. 46 683, 1953—47:192, 1954—48:13, 1954.
34 Prinzmetal, M; Kennamer, S R.; Shaw, C McK, Jr, Kimura, N, Lindgren, I., and Goldman, A: Circulation 7:1, 1953
35 Sodi-Pallares, D, Bisteni, A, Mediano, G A, and Cisneros, F Am Heart J 49 587, 1955
36 Scher, A M, Young, A C, Malmgren, A L and Paton, R R Circulation Res. 1:539, 1953
37. Master, A M, Friedman, R and Dack S. Am Heart J 24 777, 1942
38 Master, A M Ann Int Med 32 842 1950

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Electrocardiography

Introduction: The purpose of this chapter is to discuss the characteristics of the normal electrocardiogram and the important deviations from the normal that are observed in clinical practice. The theory underlying the electrocardiogram has been discussed briefly as it pertains to intracavity, unipolar and precordial leads. Other features of electrocardiographic theory are discussed elsewhere in this volume and in more extensive works on electrocardiography. The teaching of electrocardiography has undergone considerable change since the advent of the unipolar leads, particularly the precordial, "unipolar limb leads," esophageal and intracavity leads. These recent methods of study have done much to increase our knowledge of electrocardiography, and have given valuable data relative to the initiation of the cardiac impulse and its propagation through the ventricles in the normal and in the various pathological states. Intracavity leads have been *of help in correlating the various portions of the QRST complex with ac*tivation of the various portions of the interventricular septum and ventricular wall. A knowledge of these fundamental points is of paramount importance in understanding the various patterns in the precordial and unipolar limb leads. This newer knowledge places electrocardiography on a less empiric and a more scientific basis

THE ROLE OF THE ELECTROCARDIOGRAM IN CARDIAC DIAGNOSIS

Certain misconceptions are sometimes encountered regarding the function served by the electrocardiogram in the diagnosis of cardiac disease. These range from the opinion that it is of little value to the belief that the electrocardiogram is the final court for deciding the presence or absence of heart disease. Somewhere between these two views lies the truth. Undoubtedly this graphic method gives information relative to the heart which can be obtained by no other means. However, the physician who uses the electrocardiogram wisely will remember its limitations, and will treat the method as a supplement to and not as a substitute for a careful history, physical examination and roentgen study.

There are certain cardiac conditions in which the electrocardiogram is particularly valuable, conditions in which the information contributed by the electrocardiogram is on a par with or even more important than that contributed by clinical study. Among such conditions are (1) cardiac arrhythmias, (2) acute myocardial infarction, (3) acute pericarditis, (4) effect of certain drugs on the heart (digitalis, quinidine, potassium), (5)

acute infections (rheumatic fever, diphtheria, and other infections), (6) metabolic disorders (diabetes, thyroid), (7) electrolyte imbalance (particularly potassium and calcium), (8) ventricular and auricular hypertrophy, (9) nonspecific types of myocardial damage. The chance that the graphic method will reveal some evidence of myocardial derangement, not obtainable by other methods of examination, is so definite that no study of a heart can be regarded as complete which does not include an electrocardiogram

Among the limitations of the electrocardiographic method perhaps *the chief one is the fact that definite, even serious, heart disease may exist in the presence of a normal or a relatively normal electrocardiogram.* The use of precordial leads has reduced somewhat the number of such instances. Furthermore the degree of electrocardiographic change does not necessarily mirror the degree of myocardial disease. We must therefore adopt this point of view: When the electrocardiogram reveals unmistakable and characteristic changes, these are to be accepted as evidence of a severe cardiac disorder; when the alterations are slight or even when the electrocardiogram is normal, we are not justified on this evidence alone in concluding that no cardiac disease exists.

Another limitation lies in the fact that between the rather wide range of variations observed in normal tracings and those that clearly denote myocardial disease, there is an important group where the significance of the alterations is equivocal. Certain changes are neither entirely normal nor do they clearly represent disease. Examples of such alterations are low-amplitude T waves in limb and precordial leads with normal amplitude of QRS complexes, slurring of QRS complexes, low amplitude of the QRS complexes without other changes, and occasional ectopic beats. Such findings should be interpreted conservatively. They should not be accepted as evidence of disease unless or until some other confirmatory evidence of disease is obtained.

THE INSTRUMENT AND METHOD

Before considering the features of the electrocardiogram, we wish to discuss briefly the apparatus and the technic employed in its use.

A muscle when activated to contract produces some electrical activity, the magnitude of which depends on the size of the muscle. When the body is at perfect rest, the chiefly acting muscle is the heart, the other large masses of muscle being in a relatively inactive state. The current developed by the heart muscle is transmitted through the tissues to the peripheral parts of the body where it may be picked up by suitable electrodes and transmitted to the electrocardiograph. In the indirect or limb leads, the current that is developed and which reaches the instrument measures 1 to 3 mv. in Lead II and slightly more than that in the precordial leads.

Two types of machines are employed in taking electrocardiograms, the string galvanometer and the oscillograph models.

The string galvanometer consists of a powerful electromagnet, between the poles of which is situated a finely drawn quartz string filmed with silver, 0.002 to 0.005 mm. in diameter. The current produced by the heart

and carried to the instrument through suitable electrodes and wires passes through the string, which has a low resistance (1000 to 10,000 ohms), and produces oscillations which are magnified through a system of lenses and projected on moving sensitive paper or film where they are photographed. Time intervals of 0.20 and 0.04 second are photographed simultaneously with the oscillation of the string.

In the oscillograph type of electrocardiograph, the recording part of the instrument consists of a small mirror attached to a movable coil situated in a magnetic field. The mirror swings with the movements of this coil when a sufficiently large current enters the circuit and the reflection of the beam of light is photographed on moving sensitized photographic film or paper. The sensitivity of this instrument is increased by a three-stage vacuum tube amplifier which enables it to record the small currents produced by the heart. Its sensitivity is adjusted so that tracings may be taken without considering the patient's own skin resistance. This is due to the fact that an extremely high resistance is already present in the amplifying circuit, compared to which the resistance of the body is small in proportion. In both types of instruments the film or sensitive bromide paper is run at a usual speed of 25 mm. per second.

Several models of direct-writing machines have become available and with improvement have gained considerable popularity. The galvanometer is similar to that of the oscillograph type. The recording is accomplished by a direct ink writer or by a hot stylus melting a thin film of wax.

The records obtained are quite satisfactory and are comparable to those obtained by other machines. The advantages of the direct writers are obvious. The tracings can be read immediately; they obviate the labor and time of developing; and they are invaluable in the presence of acute emergencies, rapidly changing rhythms, during catheterization of the heart and in experimental investigation.

Occasionally, because of its greater sensitivity, the electroencephalograph (EEG) has been used to record the fetal electrocardiogram.

Technic Employed in Taking Electrocardiograms: Electrocardiographic tracings are taken with the patient in either the recumbent or sitting position.* It is important that he be made as comfortable and as relaxed as possible, avoiding tremors of the arms and legs. The distal portions of the left and right arm and left leg and portions of the precordium are rubbed with an electrode paste containing salt and a mild abrasive pumice base. German silver electrodes are firmly applied to these areas which, it is emphasized, must be well prepared.

In taking precordial leads it is important to rub the electrode paste only over the small area where the precordial electrode is to be placed; the electrode paste should be removed with a towel before applying it to another position. The electrode paste from one position should not be in contact with that of another position on the chest because this will tend to modify the portion of the heart tapped by the particular electrode.

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* Slight changes are occasionally observed in the electrocardiograms taken in these two positions In comparing electrocardiograms in the same patient, this point should be borne in mind

In taking frequent serial electrocardiograms on the same patient the following precaution should be observed: The tracings should be taken with the patient in exactly the same position and the precordial leads placed in exactly the identical spot (this may be facilitated by daubing a gentian violet spot over the various precordial positions). The purpose of this precaution is that slightly different placement of the precordial electrode will give slightly different electrocardiographic patterns which may be interpreted as resulting from an active myocardial process.

The more recent electrocardiographs have a selector switch which enables the operator to take the various precordial leads (CR, CF, and V) by merely turning the knob of the switch. This eliminates the troublesome reapplication of the various leads and also simplifies the taking of the unipolar limb leads.

The Leads: The following leads are used routinely in electrocardiographic study: the three standard leads (Leads I, II, and III), four to six precordial leads (in some patients additional precordial leads are used), and three unipolar limb leads. Occasionally esophageal and intracavity leads are also employed. These leads will be discussed below in detail.

The Standard Limb Leads: The standard limb leads consist of three leads, Leads I, II, and III. Lead I is secured by recording the electrical activity between the contacts of the right and left arm; Lead II, between the right arm and left leg; and Lead III, between the left arm and left leg

The limb leads are fairly adequate in the diagnosis of the cardiac arrhythmias and certain other cardiac abnormalities. They possess definite limitations, particularly in the diagnosis of myocardial infarction, ventricular hypertrophy, and other states. The limb leads record the cardiac potentials as they occur chiefly in the frontal plane. When the deflection makes an acute angle of the frontal plane the completeness with which this is recorded varies with the cosine of the angle that the electrical potential makes with the frontal plane. If the electrical potential occurs in a perpendicular plane it is not recorded in the limb leads.

Lead I resembles the electrical potential in the C_5 position; it is, in effect, a precordial lead, the left arm being the exploring and the right arm being the indifferent electrode. Lead I is equal to CR_5 after it has undergone decrement minus CR_1 after it also has undergone decrement in passing to the left arm and the right arm respectively.[2]

Lead II resembles the unipolar limb lead, aV_F. In Lead II the left-leg electrode may be considered the exploring electrode which records the diaphragmatic potential and the right-arm electrode the indifferent electrode.

Lead III represents the summation of the electrical potential referred to the left arm and left leg. These potentials can be better recorded separately by the unipolar leads aV_L and aV_F.

THE NORMAL ELECTROCARDIOGRAM IN THE THREE LIMB LEADS

The normal electrocardiogram consists of two portions, an auricular complex (P wave) and a ventricular complex (QRST portion). The

auricular complex or P wave consists of a round, blunt or pointed upward deflection 1 to 3 mm. in amplitude. The P wave represents the spread of the excitation wave from its origin in the SA node through the auricular muscle. It is sometimes followed by a dip called the auricular T wave, best seen in tracings of AV heart block. Normally the P wave is smooth and upright. However, there are many exceptions and variations which will be subsequently discussed.

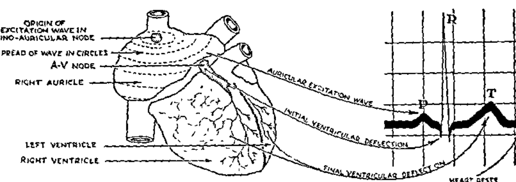


FIGURE 1. Diagram showing relation of electrocardiogram to spread of excitation wave.

The P wave is followed by an isoelectric period during which the string remains at rest except in the rare instances in which an auricular T wave is present. While the period from the beginning of the P wave to the beginning of the QRS complex represents the time required for the impulse to spread from the sinoauricular (SA) node through the auricular muscle and through the auriculoventricular (AV) node and bundle of His to the point of its division into right and left bundle branches in the upper portion of the interventricular septum, the great majority of this time is occupied by the passage of the impulse through the AV node and bundle of His. This interval, called the PR interval, normally measures from 0.12 to 0.20 second.

The QRS complex is produced by the propagation of the cardiac impulse through the right and left bundle branches, their arborizations and the Purkinje fibers to the muscle of the ventricles; at the termination of the QRS complex the entire ventricular muscle has been involved by the excitation process. The duration of the ventricular complex should not exceed 0 1 second.

As in the case of the P wave, the normal limits of variation of the QRS complex are wide. For instance, the absence of either the Q wave or the S wave or both waves is not an abnormality In a strictly normal QRS complex, there is always present an R wave which is more prominent than either the Q or S waves and which, moreover, is taller in Lead II than in either Leads I or III; it is to be remembered that slight degrees of axis deviation frequently develop in normal hearts and do not therefore, by themselves, constitute evidence of disease. So too in a strictly normal QRS complex the waves are clean-cut and unshaded However, in certain in-

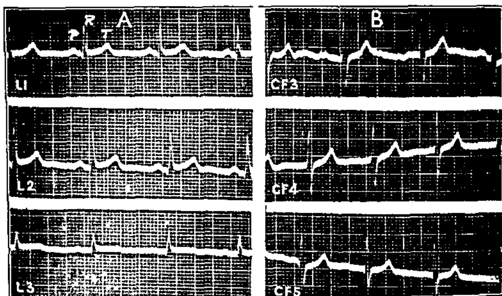


FIGURE 2 Normal limb and chest leads. In *A*, all the three customary limb leads are shown In *B*, three chest leads are illustrated As a rule, all of the numerous chest leads are not made routinely The three illustrated serve nicely for routine purposes

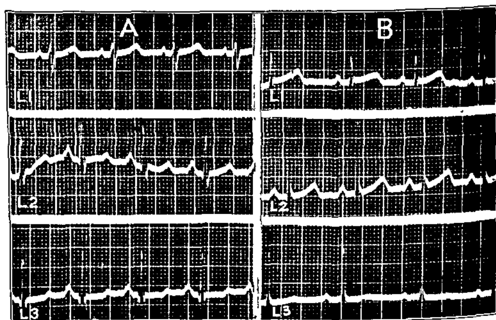


FIGURE 3. Variations in normal electrocardiograms. *A*, Note the slight right axis deviation. This configuration is frequently seen in children and healthy young adults. *B*, Note the slight elevation of the RS-T line in Lead I and the shading of the QRS complex near the base line in Lead II. Both of these changes are seen in individuals with normal hearts

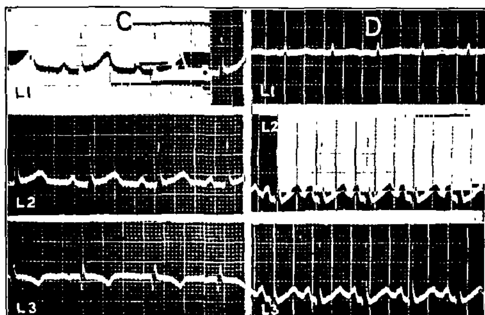


FIGURE 3 *C*, Note the Q waves in Lead III, the inverted T waves in Lead III and the inverted P waves in Lead III When confined to Lead III, these changes
f all waves in Lead I. This
is normal in the other two
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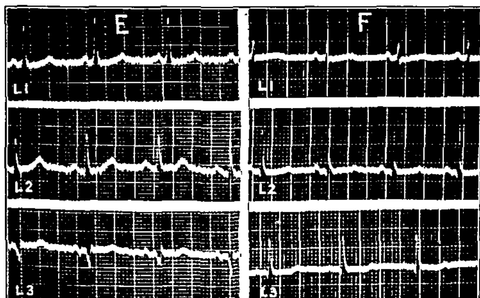


FIGURE 3 *E*, Note the slight left axis deviation and the somewhat notched QRS complexes in Lead III These changes are seen in entirely normal hearts *F*, Note the low amplitude of the T waves in all three leads. This configuration may exist in the presence of a normal heart It is frequently seen in tall individuals whose hearts are long and ptotic

stances, shading or even notching is seen in apparently perfectly healthy hearts. These and other variations will be discussed later.

The T wave is the terminal portion of the ventricular complex and represents the retreat of the electrical activity in the ventricle as contrasted to the QRS complex which represents the stage of invasion. It consists of a blunt, rounded, upward deflection rising gradually from the isoelectric line to a height of 3 to 8 mm. and then sloping downward to the base line. The T wave is normally an upright wave. However, since the T wave is so frequently inverted in Lead III in normal individuals, this cannot be considered as an abnormality.

While one may speak of a normal electrocardiogram and associate that statement with a certain definite configuration of the complexes in the electrocardiogram, *one should remember that like the human face, no two electrocardiograms are identically alike.* It is best, therefore, to think in terms of the "normal range" of the electrocardiogram since there are so many normal variations and deviations. Failure to realize the wide limits of the normal electrocardiogram is one of the chief causes of the misuse of this method. Fig. 3 illustrates some of the variations shown by normal tracings.

Relation of Ventricular Complexes in the Three Indirect Leads: It has been shown by Einthoven[14] that in the limb leads the waves in Lead II represent an algebraic summation of those in Leads I and III. With upright complexes in all leads, the R waves and T waves are of greatest amplitude in Lead II. In the presence of right and left axis deviation, the amplitude of these complexes varies, depending on their relative positivity or negativity in Leads I and III.

The QT Interval: The distance between the beginning of the Q wave and the end of the T wave represents electrical systole. It is believed that this interval is the best measurement we have for the duration of electrical systole. While the QT interval (electrical systole) corresponds fairly closely with the value of mechanical systole as determined by heart sound records, this correspondence does not hold when the QT interval is abnormally shortened or lengthened. Mechanical systole is longer in the former and shorter in the latter. The QT length is a function of the heart rate, being shorter for faster rates and longer for slower rates. The value for the normal QT interval has been established by Bazett[15] where $S^{\circ} = K\sqrt{c^{\bullet}}$, the constant K being 0.37 for men and 0.40 for women. Fridericia's[16] formula is $S = 8.22\sqrt[3]{c}$ and Hegglin and Holtzman's[91] $S = 0.39\sqrt{c}$ for both men and women. The variation in the calculation of systole by these different methods is slight and for practical purposes may be disregarded.

Comparison of Time Relations of the Electrocardiogram with Certain Mechanical Events. *The Excitation Process:* The relation of the electrocardiogram to heart sounds is of both theoretical and practical import. The first heart sound begins in man from 0.009 to 0.039 of a second after the beginning of the QRS complex. The relation of the T to the second sound is variable; it may fall 0.03 second before or after the second sound.[7]

° s = length of systole. • c = cycle length.

TABLE I

CALCULATION OF ELECTRICAL SYSTOLE BY BAZETT'S FORMULA $S = K\sqrt{c}$

Cycle length in seconds	*Square root of cycle (R-R interval)*	*Duration of Systole*	
		X 0.37 (men)	*X 0.40 (women)*
0.40	0.63	0.233	0.252
0.42	0.65	0.239	0.260
0.44	0.66	0.242	0.264
0.46	0.67	0.250	0.268
0.48	0.69	0.255	0.276
0.50	0.70	0.259	0.280
0.52	0.72	0.266	0.288
0.54	0.73	0.270	0.292
0.56	0.74	0.274	0.296
0.58	0.76	0.282	0.304
0.60	0.77	0.285	0.308
0.64	0.80	0.296	0.320
0.66	0.81	0.299	0.324
0.68	0.82	0.303	0.330
0.70	0.83	0.307	0.332
0.72	0.85	0.315	0.340
0.74	0.86	0.318	0.244
0.76	0.87	0.322	0.348
0.78	0.88	0.326	0.352
0.80	0.89	0.329	0.356
0.82	0.90	0.333	0.360
0.84	0.91	0.337	0.364
0.86	0.92	0.340	0.363
0.88	0.93	0.344	0.372
0.90	0.95	0.348	0.376
0.92	0.96	0.352	0.380
0.94	0.96	0.355	0.384
0.96	0.97	0.359	0.388
0.98	0.98	0.363	0.392
1.00	1.00	0.370	0.400

The upstroke of P precedes the upstroke of *a* in the human jugular curve by from 0.10 to 0.15 second. The upstroke of R precedes the upstroke of *c in the human jugular by from 0.10 to 0.15 second.*

It therefore appears that the electrical events definitely precede the actual mechanical contraction of the heart. This type of observation forced early investigators to conclude that electrical currents that produce the waves of the electrocardiogram are not produced by the actual muscle contraction but are the result of some process in the muscles that precedes and in some way prepares the muscles for contraction. This somewhat hypothetical process is referred to as the excitation wave or process. This view has never been entirely abandoned but Einthoven[6] did greatly reduce the time interval between the electrical and mechanical events by more refined instruments.

Note: The normal and abnormal features of precordial leads are discussed together on pages 1305-1318.

ABNORMALITIES AND VARIATION OF THE INDIVIDUAL WAVES IN THE LIMB LEADS AND CERTAIN TIME INTERVALS

The P Waves. ***Decrease in amplitude*** of the P wave is observed in cases of vagal stimulation, *e. g.*, after carotid sinus pressure, as a result of digitalis and spontaneously, especially in Lead III, during slowing of the heart at the end of expiration. At times, it occurs without reason in hearts that are apparently normal In some or all of these circumstances, it may be due to the shifting of the pacemaker from the head to the tail of the sinoauricular node. Decrease in amplitude has also been observed in hypothyroidism and myxedema, and we have observed this in cases of auricular dilatation and hypodynamic states of the auricle.

While the change may at times result from disease, actually this finding has little or no practical value.

Increase in Amplitude of the P Wave: This occurs in some, but by no means all, cases of auricular disease, particularly in mitral stenosis; in such cases the P wave is usually notched and its base broadened. Increase in amplitude without widening of the auricular complex is occasionally seen in hypertensive hearts and as a result of toxemia; increased amplitude in Leads II and III is sometimes observed in cor pulmonale. Increased amplitude of the P wave is usually considered to be the result of dilatation of the auricles.

Inversion of the P Wave: One of the factors that determine the shape of a wave is the direction the contraction process follows through the muscle. When the impulse arises in the sinoauricular node and follows the usual direction through the auricular muscle, the resulting P wave is upright. When the origin of the impulse is definitely away from the sinoauricular node, the course followed through the auricular muscle is an abnormal one, and the resulting P wave is inverted or at least differently shaped from the normal P wave. Since an abnormal or ectopic site of origin of the impulse is the essential feature of such disturbances as auricular extrasystoles, auricular paroxysmal tachycardia and AV nodal rhythm (Figs. 13 *E* and 19 *A*, *C*, and *E*), inversion of the P wave is common in these arrhythmias. It is also present in the rare instance of retrograde beats where ventricular impulses are transmitted backward through the junctional structures to reach the auricles (Fig. 19 *C*).

In supranodal or coronary sinus rhythm the P wave is flattened or of diminished amplitude in Lead I, inverted in II and III and in precordial leads. PR intervals range from 0 10 to 0.17 second. This condition has been observed in rheumatic carditis, digitalis effects, and in older patients with overactive vagal tone.

While inverted P waves always suggest and usually result from an ectopic origin of the impulse, it must be remembered that there are exceptions. Inversion of the P waves in Lead III is common and has no significance (Fig. 3 *C*). Occasionally it occurs in Lead II and even in Lead I without any demonstrable cardiac abnormality. When it results from an ectopic origin this change will be accompanied by some irregularity, as in auricular extrasystoles, or by some change in the rate, as in auricular paroxysmal tachycardia and nodal rhythm.

The change, therefore, is usually of considerable significance, but at times may have no practical meaning. The latter is always the case when the change is confined to Lead III.

Notching of the P Wave: If of slight or moderate degree this is a sign usually thought to be of no great importance since it is said to occur frequently in nondiseased hearts. Notching in Lead III alone is undoubtedly

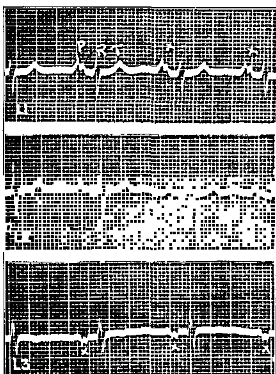


FIGURE 4 Notched P waves· The P waves in Lead I are markedly notched and their base is quite broadened Such P waves are almost always a result of rheumatic disease of the auricular muscle

seen frequently with normal hearts and is therefore of no significance. The same is true to a lesser extent when the change is present in Lead II alone or in Leads II and III. *When the P wave of Lead I is definitely and unmistakably notched, auricular muscle disease is nearly always present* (Fig. 4). The most frequent cause of the latter is the acute myocardial involvement of rheumatic fever or the later chronic stage. Less commonly, notching develops in hypertensive,[19] arteriosclerotic and syphilitic heart disease and occasionally is produced by digitalis and quinidine sulfate.

Notching of the P waves is said to result from delayed excitation of the left atrium and is usually associated with dilatation and damage of the auricular muscle.

Absence of P Waves: Unquestionably the commonest condition causing absence of P waves is auricular fibrillation in which these waves are replaced by small oscillations referred to as "f" waves which occur at the rate of from 400 to 600 per minute (Fig. 17). In a closely allied condition,

auricular flutter, there are no P waves, strictly speaking, but a series of regular fairly large oscillations occurring at a rate of from 220 to 370 per minute. In AV nodal rhythm arising in the middle portion of the AV node, the P wave is not seen but, of course, is not absent as it occurs synchronously with, and is therefore hidden by, the QRS complex (Fig. 19 *B*). In intra-auricular block and auricular standstill, the P waves are also absent; the former has been reported as a toxic quinidine effect and the latter has been observed during syncopal and Stokes-Adams seizures. Neither condition is common.

Abnormalities of the PR Interval: The PR interval is measured from the beginning of the upstroke of the P wave to the beginning of the Q wave, it normally varies from 0.12 to 0.20 second. Values above 0.20 and below 0.08 are considered abnormal. When the PR interval exceeds 0.20 of a second, the earliest grade of AV heart block is present (Fig. 18 *A*).

The PR interval is shortened in cases of upper nodal rhythm and nodal extrasystoles (Fig. 19). It is also shortened in the presence of a recently described rhythm consisting of short PR intervals with prolonged QRS complexes occurring in healthy young people prone to paroxysmal tachycardia, discussed in detail on pages 1333-1334[20,21] (Fig. 46). It may appear to be shortened at times when the auricles and ventricles are beating independently, as in complete AV block and ventricular escape. This is, of course, not a true shortening of the PR interval. Prolongation of the PR interval is discussed under Auriculoventricular Heart Block, pages 1270-1273.

Abnormalities of the QRS Complexes. *Prominent Q Waves:* The Q wave, if present in Lead I, usually measures 1 to 3 mm. An increase in amplitude of the Q wave to 4 or 5 mm. with a rather tall QRS complex is observed in some cases of hypertension with left ventricular hypertrophy. An increase in amplitude of Q_1, either absolute or relative in proportion to the height of the R wave, is frequently observed in an acute anterior myocardial infarction (Q_1T_1 type) which involves the anterior portion of the left ventricle including the interventricular septum. This wave may remain permanently (Fig. 5 *A*).

A Q wave in Lead III may be observed in entirely normal individuals whose diaphragms are elevated. It is frequently produced by this mechanism as a transient event in pregnancy. Since moderate degrees of right axis deviation are sometimes present in normal hearts, small Q waves present in Lead III in this association have no pathologic significance (Fig 3 *C*). When Q waves are present with undiseased hearts, this wave usually does not exceed twenty-five per cent of the amplitude of the ventricular complex[22] and is usually materially decreased or made to disappear entirely by deep inspiration. A Q wave exceeding the amplitude of the QRS complex in Lead III, by twenty-five per cent or more (except in right axis deviation), is observed in the following conditions: in the acute stage of posterior myocardial infarction (Q_3T_3 type) (Fig. 54), in hypertension, angina pectoris or coronary artery disease.[23] In posterior infarction, a Q_3 is often associated with a prominent Q wave in Lead II. The presence of these deflections in Leads II and III is due to the transmission of the electrical

potentials of the posterior surface of the heart to the diaphragm, and this is transmitted to the left leg. The left-leg electrode, as far as the posterior wall of the heart is concerned, may be said to aid as an exploring electrode in the sense that this term is applied in the case of precordial leads. The presence of a prominent Q wave in Lead II in posterior infarction indicates that the infarct has involved the entire depth of the posterior wall of the left ventricle, and the left-leg electrode is recording endocardial

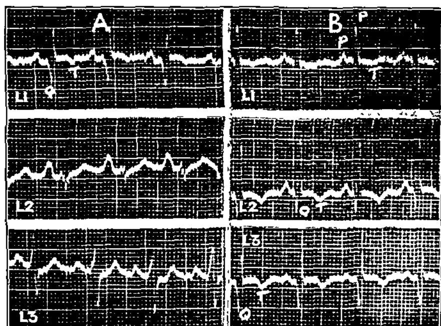


FIGURE 5 Prominent Q waves not associated with acute coronary occlusion· In *A*, the Q waves of Lead I are quite prominent In *B*, the Q waves of Leads II and III are prominent. Such Q waves are frequently a manifestation of severe myocardial disease. In both cases illustrated, the history suggests that there may have been an acute coronary occlusion at some time in the past. The Q waves in both instances are permanent changes (see discussion on Q waves in unipolar leads

potential. In addition, definite abnormalities of the T waves and RS-T segments are observed in Leads II and III; in the stage of acute infarction the RS-T segment is elevated; later the T wave becomes inverted and with healing often becomes upright. While the inverted T wave often persists (Fig. 5 *B*), a prominent Q_2 and Q_3 may diminish and may entirely disappear with healing of the infarct. The significance of Q waves in Lead III or Leads II and III can best be determined by correlation with findings in the precordial and unipolar limb leads. This will be discussed under these headings.

Abnormalities in Amplitude of the QRS Complexes. *Increased Amplitude:* Increased height of the QRS complexes in an upright direction may not be of great consequence unless the height is considerable. Markedly high amplitudes in certain leads are observed in the presence of left ventricular hypertrophy, usually associated with hypertension.

Low Amplitude: Decreased height of the ventricular complexes is often of significance. Abnormally low amplitude is said to exist when the height of the ventricular complexes is no more than 5 mm. in either of the three customary limb leads. It is of no significance when low amplitude is present *in one lead only (Fig. 3 D). The importance of low amplitude in the limb* leads must be regarded as equivocal since it not infrequently exists, in at

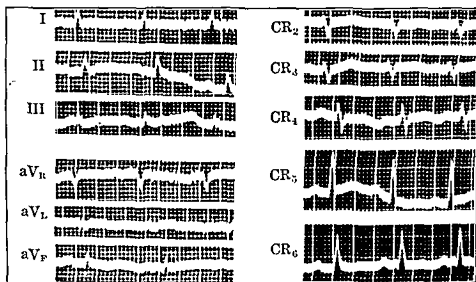


FIGURE 6 Low voltage in limb and precordial leads in patient with anasarca Note the diminished amplitude of the QRS complexes, the flattening of the T waves in the limb leads and in CR_2, CR_3 and CR_4, and low amplitude in CR_5 and CR_6

least moderate degrees, in persons with normal hearts, especially when there is accompanying obesity. Generally, however, this change is associated with, and is a result of, some forms of cardiac abnormality. Its usual cause is myocardial failure accompanied by edema, as a result of which the heart current is widely dissipated and less voltage reaches the string of the galvanometer. Low amplitude also is seen at times in myocardial disease without much edema and is occasionally associated with edema of noncardiac origin.[25] When low amplitude curves are the result of edema, the change is often reversible, the normal amplitude returning with the disappearance of the excessive tissue fluid. Other conditions in which low amplitude complexes occur are myxedema and pericardial effusion. Abnormally low amplitude of the ventricular complexes (below 5 mm.) may be present in Lead II alone, in the presence of left or right axis deviation and in right and left bundle-branch block. The change has no significance under these circumstances unless the low amplitude complex in Lead II is bizarre. Small bizarre complexes shaped like the letter M or W are usually seen in patients with coronary disease and angina pectoris.[26]

When low amplitude of the ventricular complexes (below 5 mm.) is present in the precordial leads in addition to the limb leads, the finding is of considerable importance. This combination was observed by us[125]

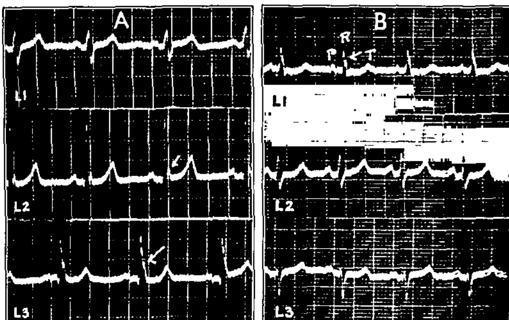


FIGURE 7 Notching of the
confined to Lead III, *A*. It
base line even in Lead II or
tricular complexes as shown
the notching in Lead I is ne
cance of such notching is sometimes uncertain

only in the presence of severe myocardial damage, usually secondary to advanced coronary artery disease. The low amplitude, to be significant, should occur in all precordial leads, particularly V_1, V_2, V_3, V_4, and V_5.

Slurring and Notching of the QRS Complexes: When not accompanied by widening these are not abnormal or suggestive of disease when confined to Lead III (Fig. 3 *E*); they may have no significance even when they are present in Leads I and II if they are located near the base line (Fig. 7 *A*) or if the amplitude of the QRS complexes is diminished (Fig. 7 *B*). However, if present near the apex of the QRS complexes in Leads I and II, when these complexes are at least moderately large, they are usually the result of some myocardial abnormality (Fig. 7 *C*). Notching of the QRS complexes is, of course, a common and almost essential feature of ventricular extrasystoles, intraventricular and bundle-branch block. In these conditions, however, there is accompanying widening of the QRS complexes.

Alternation in amplitude of successive QRS complexes without other changes in the complex (true electrical alternation) is quite rare with normal heart rates. With abnormally rapid rates (*e. g.*, paroxysmal tachycardia) the finding is not uncommon (Fig. 14). It may be associated with other manifestations of electrical alternation, *e. g.*, alternation of the PR interval or the height of the T wave. It may or may not be associated with mechanical alternation as manifested in the radial pulse.

Widening of the QRS Complexes: Study of large numbers of tracings has shown that in the majority of normal individuals, the width of the QRS complexes varies between 0.06 and 0.08 second, and that a width greater than 0.10 second generally indicates some myocardial abnormality. However, it is to be remembered that this small interval is sometimes difficult to measure and may be increased by improper technic. *Therefore one should be quite certain that real widening is present before any diagnosis is made on this finding alone.* Definite increase in width of the QRS must indicate an asynchronous activation of the two ventricles; it is present mainly in ventricular extrasystoles and in paroxysmal ventricular tachycardia and in bundle-branch block. In the latter condition, the ventricular complexes should be definitely widened. It has been stated on sound grounds that the QRS complex is at least 0.14 second in duration in *definite complete bundle-branch block. However, lesser grades* of widening (between 0.10 and 0.14 second) represent disease. They may be produced by varying grades of intraventricular conduction defects, by ventricular hypertrophy, ventricular dilatation, or by a combination of these factors. True bundle-branch block should not be diagnosed in the presence of a high ventricular rate, in which case the widening may be due to fatigue, in the sense that the diminished rest period incident to the rapid rate brings into play a potential defect in the conduction system which is quiescent so long as there is sufficient time between contractions for rest and recovery. In some instances, bundle-branch block may result from toxic factors or acute disease of the muscle and may be reversible as recovery or healing takes place.

The alterations in the QRS complexes occurring in ventricular extrasystoles, ventricular tachycardia and ventricular fibrillation will be discussed with these arrhythmias.

FIGURE 8 *Left axis deviation Note that this change may be associated with either upright or inverted T waves There is usually but not always a Q wave in Lead I In C, note the R wave in Lead I and the prominent S wave in Lead II. Either with or without inverted T waves, this configuraton is probably significant of myocardial disease*

The Electrical Axis: Since this subject has been fully discussed and illustrated in Chapter 49 we are not showing illustrations of this disturbance. The ventricular electrocardiogram is composite in the sense that it represents the superimposed electrical effects developed by both the right and left ventricles. In a normal heart, these effects are such that the R

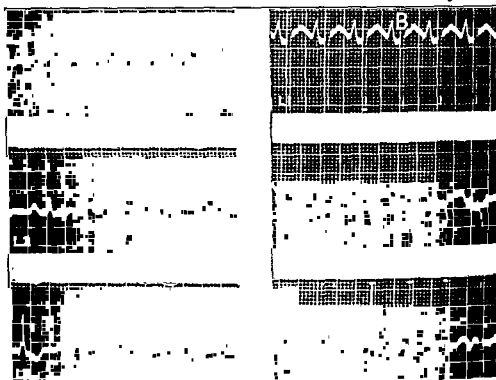


FIGURE 9 Right axis deviation· The tracing under *A* is from a case of mitral stenosis That under *B* is from a case of congenital pulmonary stenosis In the latter, note the large amplitude of the ventricular complexes and their diphasic character in Leads I and III This has been said to be characteristic of congenital disease accompanied by right ventricular hypertrophy[30]

wave of the electrocardiogram is the conspicuous wave in all three leads and is taller in Lead II than in either Leads I or III. Such an arrangement constitutes what Lewis[17] called a bicardiogram. Not infrequently one encounters patterns altogether different. That in which the R wave is taller in Lead I than it is in Lead II, while in Lead III the S wave is more conspicuous than the R wave, has been called by Lewis a levocardiogram, since this is the type of curve that is so frequently associated with left ventricular hypertrophy, and was thought by him to be the result of a preponderance of the electrical effects of the left ventricles (Fig. 8). A pattern in which the R wave is taller in Lead III than it is in Lead II and in which the S wave is more conspicuous in Lead I than the R wave, for similar reasons, was designated by Lewis as a dextrocardiogram* (Fig.

* The terms "levocardiogram" and "dextrocardiogram" are used purely in a descriptive sense We are using them as Lewis originally meant them because they are more familiar in that sense.

9). In order to discuss the factors that are responsible for these differences in pattern, it is necessary to consider the electrical axis of the heart. Since this has been fully discussed elsewhere it will not be considered here at length.

Suffice it to say that the electrical axis of the heart may be defined as the line along which the greatest electromotive forces are developed at a *given instant of time when the muscle is entering upon or recovering from* the excitatory process. This is, of course, rather complex since it is obvious that in a spherical body like the heart, the charge may be developed along many planes. The direction can, however, be related to one plane, the frontal plane of the chest, and calculated from data obtained from the three leads of the electrocardiogram.

The position of the electrical axis determines the shape of the ventricular complexes in the three leads. Normally it points downward and slightly to the left, forming an angle of 70° (on the average) with a line drawn through the shoulders (the base of Einthoven's triangle). When this is the case, the QRS complexes in the three leads take the form of what Lewis described as a bicardiogram. When the axis is deviated counterclockwise to the left until it points above a line drawn through the shoulders, the ventricular complexes in the three leads assume the characteristics of Lewis' levocardiogram. When the axis is deviated clockwise from its normal 70° to the right until it forms an angle of more than 90° with a line drawn through the shoulders, the ventricular complexes assume the configuration of a dextrocardiogram as described by Lewis.

Left Axis Deviation: This is observed in the following conditions:

1. Left ventricular hypertrophy is the commonest cause of left axis deviation. In normal hearts, the left ventricle weight is, on an average, 1.8 times that of the right ventricle This relationship is disturbed in any condition tending to cause left ventricular strain and consequent hypertrophy, *e g*, hypertension, aortic insufficiency and aortic stenosis The increase in the relative weight of the left ventricle produces a left axis deviation The electrocardiogram in this condition shows a tall R in Lead I with little or no S and a deep S with little or no R in Lead III (Fig 8 *D*).

2 In anterior myocardial infarction, a left axis deviation is often produced early, even in the absence of obvious left ventricular hypertrophy. This is probably the result of a preponderant spread of the excitation wave to other portions of the left ventricle as the result of the infarction of the anterior wall In such cases, a small R wave is present in Lead I and a deep S wave in lead III (Fig. 8 *C*).

3. A transverse position of the heart due to a high diaphragm or during a deep expiration may result in a left axis deviation, but the degree of this type of axis deviation is never marked.

4. Shifting of the heart on its vertical axis toward the right.[27] This may result from various pathologic conditions in the chest and in some instances may be produced by having the patient lie on the right side

5 In left bundle-branch block (common type) • The QRS complexes will be widened.

6 In right ventricular premature contractions,[28] and in ventricular extrasystoles arising near the base of the heart, there will be accompanying widening of the QRS complexes.

7 In some cases, particularly in small hearts weighing less than 250 Gm, no obvious cause for the axis deviation can be ascertained.[29]

Significance of Deep S Waves in Lead II with Left Axis Deviation: A deep S wave in Lead II that is much greater in amplitude than the preceding R wave is associated with an abnormal type of left axis deviation and is a sign of considerable importance (Fig. 8 *C*). It is observed in the following conditions: in myocardial disease involving the left ventricle, particularly in cases of anterior myocardial infarction, during the acute and healed stage; in hypertension; in aortic insufficiency; in angina pectoris; and in arteriosclerotic heart disease.[36] This finding is of some significance, though the electrocardiogram may be otherwise normal.

Right Axis Deviation: This is observed in the following conditions:

1. A slight grade of right axis deviation is normally present in the first few months of life and may persist into early adult life (Fig. 3 *A*).

2 Right ventricular hypertrophy is the commonest cause of right axis deviation It is produced by any factor that produces a strain and consequent relative hypertrophy of the right ventricle. Mitral stenosis is the most important cause It is also seen in right ventricular hypertrophy occurring in congenital heart disease. Other conditions tending to produce right ventricular hypertrophy and consequent right axis deviation are chronic pulmonary fibrosis, emphysema, multiple pulmonary infarction and pulmonary arteriosclerosis.

3 Rarely right axis deviation is observed following anterior myocardial infarction

4. A vertical position of the heart may give rise to a slight grade of right axis deviation and it may be produced by deep inspiration, but the degree is never marked

5 Shifting of the heart on its vertical axis toward the left may occur consequent upon various pathologic conditions in the chest. This occurs frequently in the presence of mitral stenosis It may be produced in some instances by having the patient lie on the left side

6. The uncommon type of bundle-branch block (right). The QRS complexes will be widened

7. In left ventricular premature beats there will also be widening of the QRS complexes.

8. In congenital dextrocardia there is a complete inversion of the ventricular complexes in Lead I and an interchange of those in Leads II and III.

Abnormalities of QT Interval.* ***Lengthening of the QT Interval:*** Lengthening of the QT interval is of considerable importance from the diagnostic

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* In view of the recent work concerning the site of bundle-branch block, the old theories of its production, as originally suggested by Lewis, must be revised The suggestion is made by Wilson[23] that the presence of a left axis deviation in the common type of bundle-branch block and right axis deviation in the rare type of bundle-branch block is due to the summation of the electrical forces between the interventricular septum and free wall of the left ventricle.

* See Table I, page 1243, for normal QT values

and prognostic standpoint. It may be lengthened in many conditions, the most important being hypopotassemia[37] and hypocalcemia.[91] In these conditions, the lengthening is immediately reversible by the administration of respective electrolytes. Hypopotassemia may be present in many conditions as noted on pages 1378-1379. Other conditions which result in QT lengthening are: azotemia; hypoglycemia shock; various types of myocardial disease; the result of anoxia (pulmonary embolism, coronary occlusion);

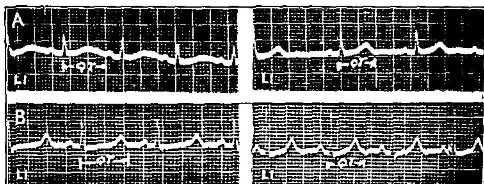


FIGURE 10 Prolongation of the QT interval· The tracings under *A* were obtained from a patient with diabetic acidosis The first strip was made shortly after emergence from coma The second strip was obtained a week later *B* shows strips of tracings from a patient with hypocalcemia The first strip was made at the height of the disturbance, the second strip, after the blood calcium had returned to a normal level.

and the action of certain drugs, particularly quinidine. While QT lengthening is observed in limb leads, it is most clearly demarcated in precordial leads CR_3, CR_4, or CR_5.

Shortening of the QT Interval: This is observed in hyperparathyroidism and as a result of the action of digitalis. In the latter condition, it is usually accompanied by characteristic depression of the RS-T interval.

Abnormalities of the T Wave. ***Variation in Amplitude:*** The T wave is increased in amplitude following exercise, occasionally in thyrotoxicosis, *in bundle-branch block and in ventricular extrasystoles. During the sub*acute stage of myocardial infarction and in patients with severe anginal seizures, the amplitude of the T wave, particularly in the chest leads, may be considerably increased. This is of practical diagnostic import.

Decrease in amplitude of the T wave below 2 mm. in Leads I and II with normal amplitude of QRS is usually due to myocardial derangement (Fig. 7 *C*). It is to be remembered that digitalis and toxic states as well as disease of the heart can produce this change. In hypothyroidism and myxedema as well as generalized edema not only are the T waves low but decrease in amplitude of the QRS complexes is also present. It is to be remembered also that a low amplitude T wave associated with a low QRS complex is sometimes observed in patients with dropped or ptotic hearts which are essentially normal *Moderate lowering of the T waves should be interpreted carefully and conservatively.*

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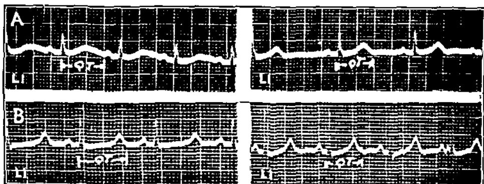


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Isoelectric or flat T waves are due to factors similar to those mentioned under decreased amplitude.

The amplitude of the T wave in limb and precordial leads is profoundly affected by the position of the patient during the time the electrocardiogram is taken (standing, sitting, or recumbent).

Diphasic T Waves: This refers to a configuration in which part of the T wave is inverted and part upright. In some instances, the first portion is inverted while the terminal part of the T wave is upright. In other instances, the first part is upright and the terminal portion inverted. Diphasic T waves generally represent a stage between normally upright T waves and completely inverted waves. Diphasic T waves, therefore, have, in somewhat lesser degree, the same significance that applies to inverted waves.

The term "diphasic" is often loosely applied to a configuration in which the T wave proper is entirely upright but the RS-T line is depressed. Such a pattern may be produced by digitalis[30] or by acute myocardial infarction as well as other factors. It is better to refer to this configuration as deviation of the RS-T segment.

Notching of the T Waves: These waves are, as a rule, rounded and smooth. Not infrequently they may appear to be notched as a result of a superimposed P wave, as sometimes occurs in paroxysmal tachycardia and AV heart block. Occasionally the T waves are genuinely notched. In other instances, this results from a pronounced U wave which closely follows the T wave[31] and gives the impression of notching.

Inverted T Waves: At least three types of T wave inversions may be described:

The Coved T Wave: When typical, the RS-T line preceding the inverted T wave is markedly convex upward and usually rises above the base line. As shown by Pardee,[32] it usually is present in acute or subacute myocardial infarction (Fig. 49 *B*). However, it is seen occasionally in other conditions.

The Beaked T Wave: The RS-T line rises slowly and may be slightly coved. At the very end, it dips downward suddenly, making the last portion of the T wave inverted. This type of inversion has the same significance that is attached to the other types of inversion, in the sense that it is associated with severe myocardial derangement. We have seen it particularly in the subacute and acute stages of myocardial infarction, in syphilitic heart disease associated with narrowing of the orifices of the coronary arteries, in the subacute stage of pericarditis and in patients with hypopotassemia.[37]

The Usual Inverted T Wave of Myocardial Disease: While these waves may vary greatly in the depth of inversion, etc., they have this constant characteristic: The RS-T segment and descending limb of the T wave is always convex upward to some extent. The latter may be slight or it may be marked and at least approach real coving. Generally, this variety of T wave is the result of severe and permanent myocardial change. Occasionally it may be the result of remediable causes such as myxedema, avitaminosis, acidosis, etc., and, therefore, may be reversible (Fig. 7 *C*).

The first two types of inverted T's may be considered to be "T waves in flux," *i. e.*, they are due to conditions that are rapidly changing and are rarely observed for more than a few weeks or months. The third type, the myocardial T wave, may be a permanent event since it usually results from forms of myocardial disease that are not likely to improve.

Regardless of the types, inversion of the T waves in Lead I or Leads I and II is always an indication of serious myocardial disease or serious myocardial derangement. Inversion in Lead II is perhaps due to myocardial disease. However, not infrequently it is seen in hearts that present no clinical evidence of myocardial disease. It therefore does not warrant a diagnosis of myocardial disease unless there is something in the examination to confirm its importance.

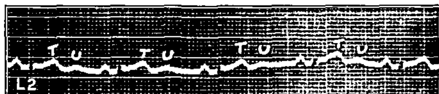


FIGURE 11 U waves (see below)

Deviation of the RS-T Segment*: A single contraction of a normal muscle produces an electrocardiogram of two distinct portions, hence it is diphasic. In the case of the ventricles of the human heart, the first phase is the QRS complex; the second phase is the T wave. The interval separating these two phases is called the RS-T segment. In a strictly diphasic curve it is essential that the RS-T line arise from the S wave at the base or isoelectric line. When this is not the case and the RS-T line comes off definitely above or below the isoelectric line, the RS-T segment is said to be deviated. This results in an electrocardiogram that at least tends to be monophasic (Figs. 49 and 50 *B*).

Monophasic type curves, that is to say curves in which the RS-T segment is definitely deviated, are among the most important findings revealed by the electrocardiogram for the reason that monophasic curves are the result of currents of injury, which in turn are produced in the human heart chiefly by coronary occlusion. The recognition of monophasic curves is the essence of the electrocardiographic diagnosis of coronary occlusion, the field in which this graphic method is at its brilliant best.

One also encounters RS-T deviation in other conditions. It may be prominent in pericarditis where it probably results from accompanying muscle injury. It is also produced by digitalis and in certain types of anoxia; the mechanism of its production in these conditions is attributed to currents of injury involving the subendocardial portion of the ventricles.

* Actually small deviations of the RS-T segment may not be significant, they may occur in normal hearts To be suggestive, by itself, the deviation must be more than 2 mm When in doubt, serial tracings are indicated, these will reveal alterations in the "abnormal" type only.

U Waves: The U wave is an upward peak occurring after the T wave, often observed in normal tracings (Fig. 11). We did not describe it as a part of the normal electrocardiogram since it is not a constant feature. It usually is considered to occur during ventricular diastole. However, Einthoven[96] was of the opinion that this wave indicates persistence of contraction in some fibers into early diastole. The U wave has an amplitude usually of 1.5 mm., begins 0.04 second after the end of the T and continues for 0.16 to 0.24 second with an average duration of 0.20 second. No significance has been attached to the wave. Recently, however, Nahum and Hoff[31] have suggested that the U wave is part of the ventricular complex, is produced during systole and represents the supernormal period of recovery. This is a short period immediately following recovery from electrical excitation when the ventricle is most susceptible to ectopic beats. They believe that the majority of extrasystoles fall on the U wave or the part of the cycle where it occurs. They found inversion of the U wave or fusion of the U wave with the T wave only in patients with damaged hearts. We have recently observed, as have others, unusually prominent U waves in the presence of hypopotassemia associated with alkalosis.[37] These disappear as the serum potassium level returns to normal.

THE ARRHYTHMIAS

Before discussing the arrhythmias, we should like briefly to refer to some of the important features of the normal cardiac mechanism.

The Normal Mechanism

All portions of the heart muscle, including the nodes and specialized conducting tissue, possess certain fundamental properties. While these properties are common to all heart muscle, certain properties are more highly developed in certain parts of the muscle than in others

For example, excitability and rhythmicity are more highly developed in the muscle fibers that constitute the sinoauricular node. For this reason this structure is the normal pacemaker of the heart; with a normal mechanism impulses arise in this structure quite regularly and at a rate usually between 60 and 120 per minute. From the sinoauricular node, the impulse spreads radially through the auricular muscle at a rate of approximately 1000 mm. per second, and in doing so produces the P wave of the electrocardiogram. The impulse then enters the AV node. This muscle, like other cardiac muscle, possesses the common fundamental properties but is specialized in that its refractory period is long and its ability to conduct poor (only 200 mm. per second). Most of the PR interval is occupied by the passage of the impulse through the AV node and main bundle of His Having passed these structures, the impulse enters the branches of the His-bundle and the Purkinje fibers where its passage is rapid (4000 mm. per second) since the ability to conduct is very highly developed in these structures. The impulse then enters the muscle of the ventricles which contracts. Once contraction is completed, the muscle returns to, and remains in, a resting state until another impulse is generated.

Among the important features of a normal mechanism, therefore, are:

1. Regularity of the formation of sinus impulses and the resulting P wave The P waves are upright
2. A rate that is within the normal range (between 60 and 120, approximately).
3. Every P wave is followed by a ventricular response
4. Every ventricular complex is preceded by and will be a response to a P wave.
5. The PR interval is between 0 08 and 0 20 second.
6. The impulse reaches both ventricles simultaneously and the QRS complexes are of normal duration.

When any of these features are departed from, the mechanism is no longer normal. Such a departure constitutes a cardiac arrhythmia.

Classification of Arrhythmias

The arrhythmias may be divided into four groups, according to the portion of the heart in which they arise.

Disturbances of Rhythm Originating in the Sinoauricular Node: Sinus arrhythmias, sinus bradycardia, sinoauricular heart block and prolonged grades of cardiac standstill.

Disturbances Originating in the Auricles: Auricular extrasystoles, auricular paroxysmal tachycardia, auricular flutter, auricular fibrillation and auricular standstill or intra-auricular block

Disturbances Originating in the AV Node: AV heart block (prolonged PR interval, *increasing grades of partial block and complete AV block*), *nodal rhythm (may be the result of abnormal function of SA node)*, AV dissociation, ventricular escape, nodal extrasystoles and nodal paroxysmal tachycardia.

Disturbances Arising in the Ventricles: Ventricular extrasystoles, ventricular paroxysmal tachycardia, ventricular fibrillation and pulsus alternans.

Sinus Arrhythmia

The usual type of sinus arrhythmia is characterized by a gradual waxing and waning of the cardiac rate which varies with the phases of respiration. *The rate increases with inspiration owing to a diminution in vagal effects* and decreases with expiration as a result of increased vagal action. This type is usually seen in young individuals in whom it is physiologic (Fig. 12 *A*). Another type of sinus arrhythmia is observed in which this irregularity occurs independently of respiration. This form is often a result of toxic digitalis effects.

The impulse originates in the normal pacemaker and is transmitted normally through the heart. The only electrocardiographic change is the variation in time between successive auricular (P) waves. This irregularity is abolished by any factor that increases the heart rate, *e. g.*, exercise, emotion or atropine. Its presence carries with it no definite pathologic significance. However, in older patients it is said to be associated with arteriosclerotic processes in the heart muscle.

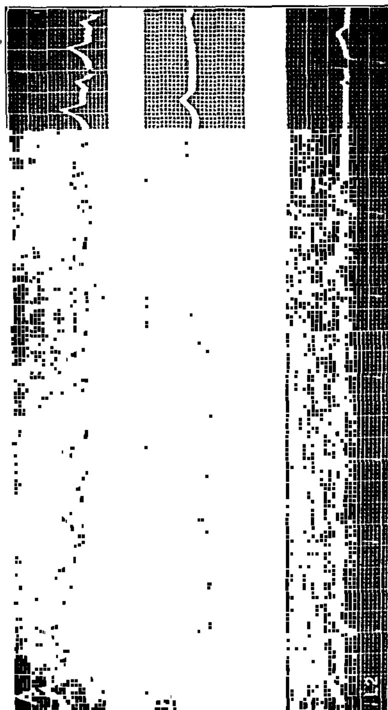


FIGURE 12 Disturbances of the normal sinus mechanism *A*, Sinus arrhythmia. Note the marked slowing of the rate of formation of P waves, and then the gradual increase in rate *B*, Sinus bradycardia P waves occur fairly regularly, but at an abnormally low rate *C*, Sinoauricular heart block. Note that the rate of formation of the P waves suddenly becomes halved

Sinus Bradycardia

This is characterized by a low sinus rate, 40 to 50 per minute. No other abnormalities are noted (Fig. 12 *B*). Although occasionally observed in young individuals with excessive vagal tone, it is more frequently observed in older patients with varying degrees of arteriosclerosis. The sinus rate can usually be increased by atropine or other factors which diminish vagal tone.

Sinoauricular Heart Block

This is recognized in the electrocardiogram by the fact that the interval between successive P waves is exactly or almost twice the usual PP interval. An auricular as well as its accompanying ventricular complex is lost (Fig. 12 *C*). Several types of sinoauricular block are observed: (1) The irregularity may be observed for a few cycles; (2) the rate may be suddenly halved, dropping, for example, from 75 to 36 per minute, the slow rate persisting for several minutes or more; (3) this disturbance may be present for long periods of time and may be the underlying mechanism for long-continued bradycardia.

The mechanism of this irregularity is poorly understood. It is apparently associated with increased vagal tone and may be abolished by exercise or atropine. It carries with it no pathologic significance as a rule. However, in older patients it is often associated with arteriosclerotic change; in the latter type of patient, it may also be produced by digitalis effects.

Prolonged Sinus Pauses (Cardiac Standstill)

If for any reason the sinus node fails to initiate the cardiac impulse, the AV node, because it also possesses the property of rhythmicity to a degree only slightly below that of the SA node, soon escapes and initiates the heartbeat slowly and rhythmically until the SA node can again resume its function as pacemaker.

Ordinarily, the AV node is prompt to assume its pacemaker function. In certain instances, however, this may be delayed with the result that there is complete cardiac standstill. This may be of sufficient duration to produce dizziness or even syncopal attacks. These pauses are the result of vagal effects which may either occur spontaneously as a result of reflex disturbances or be produced in susceptible individuals by carotid sinus pressure. Such seizures can usually be abolished by atropine or ephedrine.

Auricular Extrasystoles

In auricular extrasystoles, the impulse arises prematurely from an ectopic focus in the auricular muscle outside the sinus node. Hence they are frequently referred to as premature or ectopic beats. From its point of origin, the impulse travels to the other portion of the auricular muscle and is then propagated through the AV node and ventricles in a normal manner. Since the impulse arises from a point outside of the sinus node, it will travel through the auricle in an unusual direction; the P wave therefore possesses an abnormal contour. It may be splintered, notched, diphasic or inverted (Fig 13 *D*, *E*, *F*) The PR interval is usually not shortened. The farther the ectopic focus is situated from the sinoauricular node, the more abnormal is the shape of the premature P wave. When, as is frequently the case, the ectopic focus is quite near the sinoauricular node, the premature P wave may be nearly or identically like the normal sinus P wave (Fig. 12, *D* and *F*). The other electrocardiographic feature is, as has been implied, the fact that the P waves occur prematurely.

The pause following the auricular extrasystole is usually not compensatory in the sense that the interval between the normal beats immediately

preceding and succeeding the extrasystole is identically the same as the interval between three normal beats. However, there frequently is some pause after the premature beat.

Almost always an auricular extrasystole is followed by a ventricular response. Occasionally, the auricular wave occurs so prematurely that the ventricle will not have recovered sufficiently to respond. Under these

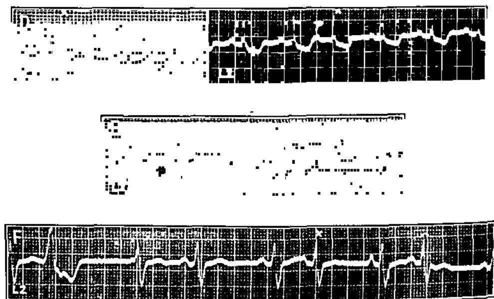


FIGURE 13. Auricular extrasystoles are shown in *D, E,* and *F.* Note that the premature P waves are upright in *D* and *F.* In *E,* an inverted P wave is shown In *E,* a premature P wave is superimposed on the fourth T wave This premature auricular beat occurs so early that the ventricles cannot respond to it

circumstances, one sees the very premature P wave without an accompanying ventricular response. The QRS complexes following the premature P wave are usually of normal contour since the shape of the ventricular waves is determined solely by the course of the impulse within the ventricles, which in no way is influenced by the site of origin of the impulse within the auricles. If, however, there is some potential defect in one of the branches of the His-bundle, the diminished rest period induced by the premature beat may bring this defect into play with the result that the ventricular complex of the auricular extrasystole may be as widened and notched as a ventricular extrasystole. Auricular extrasystoles may occur as isolated beats, coupled to normal beats, or in series of two or more. When six or eight of such beats occur in succession they constitute a short paroxysm of auricular tachycardia.

The cause and significance of auricular extrasystoles is often difficult to determine. This disturbance is often observed in normal hearts. On the other hand, these premature beats are frequently a result of disease of the auricular muscle: They are not infrequently observed in rheumatic fever, other infections and in hypertensive and arteriosclerotic hearts *The*

occurrence of extrasystoles is therefore not pathognomonic evidence of heart disease. On the other hand, it is somewhat suggestive. Its significance must be determined by other studies.

Auricular Paroxysmal Tachycardia

Paroxysmal auricular tachycardia consists of a rapid succession of auricular extrasystoles. The rate during the paroxysm varies approximately from 140 to 220 per minute (Fig. 14).



FIGURE 14 Auricular paroxysmal tachycardia The rate during the disturbance is 200 per minute Note the end of the paroxysm followed by a postparoxysmal pause with restoration of normal rhythm The initial cycle of normal rhythm shows coupled auricular extrasystoles. Note also the alternation in the amplitude of the ventricular complexes during the rapid rate "electrical alternation"

The P waves of the paroxysm show an abnormal form similar to that of an auricular extrasystole. With very rapid rates, the P waves are often superimposed on the T wave, making its recognition difficult or impossible. When this is so, the certain identification of the disturbance can be made only if one secures the beginning or the ending of a paroxysm. The QRS complex is usually normal in shape. In some instances, widening of the ventricular complexes occurs, owing to fatigue of the intraventricular conducting mechanism incident to the high rates and resulting diminished rest period. Usually the ventricles respond regularly to every auricular impulse. It is not difficult to see how this might not be the case if there is any disease of the AV node or if this structure is strongly under the influence of digitalis. It is not unusual to encounter some degree of AV heart block with auricular paroxysmal tachycardia.

The paroxysms of tachycardia may last from a few seconds to a few days They start and end abruptly There may be a fairly long "postparoxysmal pause" between the ending of the paroxysm and the resumption of normal impulse formation by the sinus node. The paroxysms can be terminated in a large percentage of instances by pressure over the carotid sinus.

No more is known concerning the cause of auricular paroxysmal tachycardia than of auricular extrasystoles. *However, it is well established by clinical observation that this disturbance frequently (perhaps usually) develops in individuals with no evidence of organic heart disease.* Often persons who have this disturbance for years live to old age without developing any other evidence of cardiac disease. While very little is known of the fundamental cause, it is well established that the attacks are precipitated often by extracardiac factors, particularly gastrointestinal disturbances and nervous or emotional influences.

Auricular Disturbances Dependent on a Circus Movement

The Circus Movement*: With a normal cardiac mechanism, an impulse arising at a single point (the SA node) spreads until it has involved the entire muscle. With the completion of the contraction thus produced, the muscle remains at rest until another impulse arises in the SA node and repeats the process. An entirely different type of mechanism, known generally as the circus movement, exists quite frequently in the abnormal heart and is responsible for two important disturbances of rhythm: auricular flutter and auricular fibrillation. With a circus movement, the impulse that produces contraction becomes established in a continuous circular ring of muscle. Having once activated the fibers of this ring of muscle, the process does not end and await the genesis of another impulse: The same impulse *re-enters the muscle it has already traversed, thus producing a continuous* progressive contraction of one segment of the fibers of the ring of muscle after another. This may continue indefinitely provided the muscle immediately in front of the forward moving crest of the wave has recovered from its refractory state. Failure of this recovery will end the circus movement; the quinidine treatment of auricular flutter and auricular fibrillation is based on the fact that this drug prolongs the refractory state and thus ends the movement.[34]

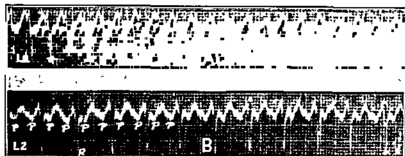
There is reason to believe that the rings of muscle in which a circus movement becomes established are around the mouths of the venae cavae. Electrical changes in this small ring of muscle, which Lewis[35] has called the mother circus, could hardly be expected to account for all the changes seen in the electrocardiogram. According to Lewis' conception, what takes place in the mother circus is transmitted by a centrifugal-like action to the rest of the auricular muscle; it is the electrical changes developed in the latter that produce the characteristic electrocardiographic changes of auricular flutter and fibrillation.

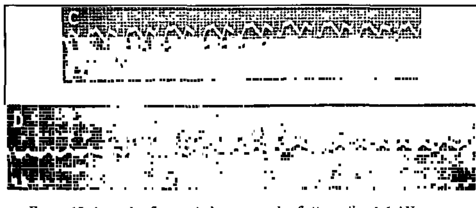
In both conditions the chief feature upon which the electrocardiographic diagnosis is based is a series of waves, each produced by the complete involvement of the muscle of the mother circus and the resulting activation of whole masses of auricular muscle. These auricular waves are really continuous oscillations since there is no isoelectric period between the deflections. The shadow of the galvanometer string is constantly in motion. This is necessarily so, since by the very nature of the circus movement the muscle of the auricle is never either entirely active or entirely inactive—some portions are active while others are at rest.

While both flutter and fibrillation apparently depend upon the same mechanism, there are differences which make the two conditions distinct. The chief factor that produces these differences is the state of the refractoriness of the auricular muscle. In flutter the muscle is in a much more completely recovered state with the result that the wave moves smoothly, rapidly and regularly, and can, from cycle to cycle, repeat the same course. This produces auricular waves that are very regular in time and shape. In auricular fibrillation, in contrast, the muscle of the circus and the auricle

* Most of the data relating to the circus movement in auricular flutter and fibrillation have been taken from the work of Lewis[17]

itself is in a state of partial refractoriness, with the result that the contraction wave moves more slowly and with difficulty and cannot always follow the same course or complete its circuit consistently in the same time interval. As a result, the waves are irregular in time and not identical in shape.





AV response The auricular rate is 280 per minute, the ventricular rate, 140 per minute *D*, Auricular flutter with complete AV heart block The ventricular rate is regular and slow (36 per minute) In all the illustrations, note the regularity in the rate and the shape of the auricular waves

Another fundamental difference is the fact that the controlling ring of muscle or mother circus is longer in flutter than in fibrillation. Therefore, in spite of the fact that the impulse travels quickly, the long circus makes the time required for its complete traversal longer. In flutter, therefore, the rate of the regular oscillations is slower than the somewhat irregular oscillations of fibrillation

The circus-movement theory underlying auricular fibrillation and flutter has been seriously questioned by Katz,[39] Scherf,[40] and most recently by Prinzmetal [41] In auricular fibrillation it has been postulated that many points in the auricle may be the site of origin of the electric potential. Recently, Prinzmetal and associates[41] have shown in dogs that the focus originating the flutter may arise in the right auricle, left auricle, or in a point between them. From this focus the impulse spreads simultaneously

to both the right and left auricles by a gradually enlarging circular wave, like a pebble thrown in a stream. They state that the mechanism underlying auricular flutter and auricular tachycardia is similar except for the difference in auricular rate. They adequately explain the effects of digitalis and quinidine on the basis of their theory.

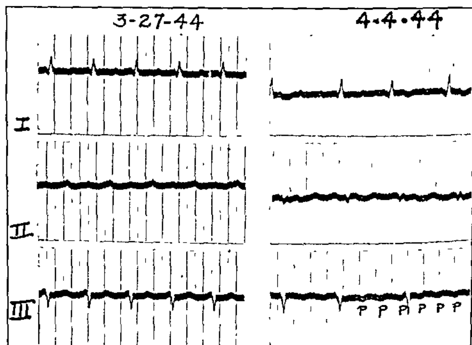


FIGURE 16 Illustrates difficulty in diagnosing auricular flutter at rapid rates (3/27/44) When the degree of AV heart block is increased (4/4/44), the diagnosis of auricular flutter becomes obvious. (Lead III.)

Auricular Flutter: Auricular flutter is not nearly as common as auricular fibrillation. In our hospital practice, we have encountered it in approximately one out of every 200 patients. It generally develops in patients with diseased hearts. Occasionally it is encountered in individuals without apparent cardiac abnormality

As we have indicated, the distinctive electrocardiographic features are the auricular oscillations. These are rarely seen plainly in Lead I but are very distinct in Leads II and III. While every oscillation is identically alike in any given lead, the shape of the oscillations varies greatly from patient to patient just as P waves do. In diagnosing flutter, it is essential that these characteristic oscillations be identified and that they be shown to be entirely regular and at a rate between 220 and 370 per minute These auricular oscillations are quite evident with slow ventricular rates—they are not always easily recognized with the usual rapid ventricular rates, for the rapidly recurring QRS and T complexes may considerably mask the small auricular waves. It is necessary to visualize what the tracing would be like if the QRS complexes were absent. As a rule this is not dif-

ficult to do; if it is thought of, flutter will rarely be missed electrocardiographically (Fig. 15).

The ventricular response to the auricular impulses is of some importance. The AV node can rarely transmit all of them to the ventricle. As a rule, the refractory period of the AV node allows it to transmit only every second auricular impulse. At times, even fewer auricular impulses pass the AV node, giving an AV ratio of 3:1, 4:1, or even higher ratios. This is usually the result of either some disease of the AV node or the action of digitalis. Under the latter circumstance, the AV ratio sometimes varies from cycle to cycle. The latter introduces no difficulty in the electrocardiographic recognition of flutter; it may make considerable difference in a clinical diagnosis.

Occasionally, as a transient event, the refractory period of the AV node becomes so shortened that it transmits every auricular impulse. Under these circumstances, the ventricle beats very rapidly; we have seen it reach a rate of 260 per minute several times (Fig. 15 *A*). In older individuals whose hearts are not very good, unconsciousness or Stokes-Adams syndrome may result from such rapid rates.

Effects of Carotid Sinus Pressure: The usual effect of carotid sinus pressure in auricular flutter is to produce a temporary AV heart block, lasting a few cycles; the auricular rate is usually unaffected. Such periods of AV block are produced more easily when this structure has been rendered more sensitive to stimulation by the administration of digitalis to the patient.

In two cases, we have been able to record the change of auricular flutter to auricular fibrillation following carotid sinus pressure.[36]

Types of Auricular Flutter: Auricular flutter may occur in a paroxysmal form or as an established flutter. The latter form is said to be present if its duration has been two weeks or more. Instances have been recorded where the flutter lasted uninterruptedly for eight years.

Effects of Drugs in Auricular Flutter: Digitalis, which is the drug of choice in the treatment of auricular flutter, usually first produces an increase in the grade of AV block, then converts the flutter to auricular fibrillation. If digitalis is then stopped, the auricular fibrillation frequently reverts spontaneously to normal rhythm. If this does not occur, the fibrillation may tend to persist unless quinidine is given to establish normal rhythm.

Occasionally, digitalis may convert auricular flutter to a normal sinus rhythm without a noticeable period of auricular fibrillation. This may occur as the result of the rather infrequent preponderance of the direct muscular over the vagal effect which tends to increase the refractory period of the auricular muscle; the mechanism of return to a normal rhythm in these rare instances is similar to that with quinidine.

Quinidine sulfate, if effectual, converts the flutter to normal rhythm without an intervening stage of auricular fibrillation; it often slows the auricular rate considerably during auricular flutter. This may fall as low as 130 per minute.

Beta methyl choline has been successfully used to change auricular flutter to auricular fibrillation by reason of its vagal stimulating effect,

but its use for this purpose is not recommended because of its not infrequent toxic action.[45]

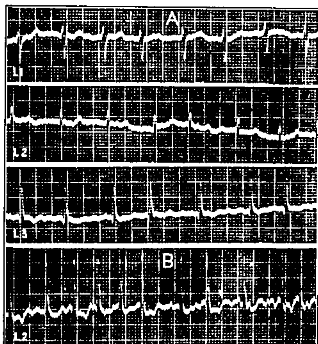
Auricular Fibrillation: Because of the differences which we have already pointed out, the auricular oscillations in auricular fibrillation (400 to 700 per minute) are much more rapid than they are in flutter and are irregular in time and shape. These characteristics of the auricular oscillations may help in the electrocardiographic recognition (Fig. 17). However, the auricular oscillations are rarely as prominent as they are in flutter. They may be present only in one lead or possibly only in an occasional cycle. Sometimes the oscillations are not visible in any indirect lead; usually they can be shown by appropriately placed chest leads. When the oscillations are absent, the diagnosis must be established by other criteria. The absence of a definite consistent P wave before each QRS complex may help. But it may be difficult to be certain even of this. The one consistent electrocardiographic finding is the one that is so prominent clinically, complete irregularity of the ventricular response to the very rapid auricular stimuli. There are instances in which the slightly irregular ventricular rhythm is not sufficiently marked to be detectable by the ear, but one usually has no difficulty in detecting the complete irregularity in the tracing. Very occasionally, the ventricles may be regular. This is usually seen where digitalis has caused complete or nearly complete AV heart block.

The application of these criteria either alone or combined usually makes the electrocardiographic diagnosis quite easy.

There are some instances in which the auricular waves are large, only slightly irregular and of a rate more like that of flutter than fibrillation. This represents a grade of circus mechanism somewhere between fibrillation and flutter. It is usually called impure flutter, though often it is closer to fibrillation than flutter.

The ventricular rate is not only irregular but in most cases of untreated fibrillation, it is rapid. Ventricular rates of 160 are common. Occasionally 200 per minute may be reached (Fig. 17 *C*—first strip). While rapid rates are the rule, slow ventricular rates, even where no digitalis has been used, may be encountered. This is particularly apt to be the case in older individuals whose AV conducting tissue has undergone degenerative changes.

The Action of Drugs in Auricular Fibrillation: The drug treatment of fibrillation is quite satisfactory. Two methods of treatment are available: (1) the use of digitalis, and (2) the use of quinidine sulfate. Since these are discussed elsewhere, they will be treated very briefly here. Digitalis has no beneficial effect on the auricular mechanism; indeed it may make the auricular oscillations more rapid by its action of shortening the refractory period. Its remarkable effects come chiefly from its action on the AV node whereby the number of effective auricular stimuli that reach the ventricles can be reduced to almost any level that one desires. Quinidine is effective through its action in entirely abolishing auricular fibrillation and restoring a normal auricular mechanism in approximately sixty per cent of the cases. It accomplishes this by prolonging the refractory period of auricular muscle so that the crest of the circus wave finds no recovered muscle to enter; the circus movement ends and normal rhythm is restored.





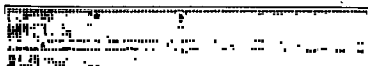




FIGURE 17. Auricular fibrillation: *A* is from a case of mitral stenosis There is a right axis deviation The ventricular rate is fairly well controlled by digitalis Note the absence of P waves and their replacement by small irregular oscillations which are called f waves Note also the total irregularity in the spacing of the RR interval *B*, Auricular fibrillation with a rapid ventricular rate, averaging 170 per minute *C*, The first strip shows auricular fibrillation with a rapid

AV heart block, due to digitalis.

Quinidine is now used chiefly in paroxysmal fibrillation or fibrillation that is known to have been established recently. It is not often used in long-established fibrillation or where the heart is severely diseased, since the restoration of normal rhythm is often temporary and severe depressing effects may occur. Moreover, in auricular fibrillation, where the ventricular rate has been controlled by digitalis, the circulation will be maintained almost but not quite as well as in a normal rhythm.[42]

Like flutter, auricular fibrillation may exist as a paroxysmal or as an established disturbance; not infrequently, it lasts for many years.

Auricular fibrillation nearly always develops in diseased hearts; its existence alone is suggestive evidence of myocardial disease. It is the commonest abnormal mechanism exhibited by severely diseased hearts, being present in about sixty per cent of all cases with heart failure. It is most frequently associated with rheumatic heart disease, although it is almost as frequently encountered in hypertensive and arteriosclerotic varieties. Hyperthyroidism not infrequently precipitates this irregularity; often it is of the paroxysmal variety. Syphilis is rare as an etiologic factor.

Auricular Standstill

Auricular standstill is characterized by absence of the auricular beating (P waves) for several cycles or for even longer periods.[97] This condition must be differentiated from nodal rhythm where the P waves may be buried in the QRS complexes. This may be elucidated by the use of a jugular pulse tracing, by the use of precordial leads taken in the C_1 position and by the use of esophageal leads.

Auricular standstill may be caused by toxic quinidine or potassium effects, by carotid sinus pressure and by reflex vagal stimulating effects from the gastrointestinal tract. In these conditions, the ventricle ultimately escapes. Total cardiac standstill may be present for varying periods of time, up to thirty seconds during Stokes-Adams seizures.

Auriculoventricular Heart Block

This term is applied to the abnormal cardiac mechanism in which an auricular impulse is delayed or completely fails to reach the ventricle. This disturbance is the result of disease or abnormal function of the AV node or bundle of His. In its simplest form, every auricular impulse reaches the ventricle but requires a longer time interval. With higher grades of block, occasional auricular impulses fail entirely to secure ventricular responses. The auricular and ventricular responses may assume a regular mathematical ratio such as 2, 3, or 4 auricular impulses to 1, 2, or 3 ventricular responses. With complete AV block no auricular impulses reach the ventricle. Complete and partial AV block show the following electrocardiographic difference: In partial AV block, every ventricular beat present is a response to a preceding auricular impulse; in complete AV heart block, ventricular beat is not a response to auricular impulses but is a response to impulses originating within the lower portion of the AV node or the ventricle.

Both complete and partial block generally occur in older individuals and are usually the result of actual degenerative changes in the AV node.

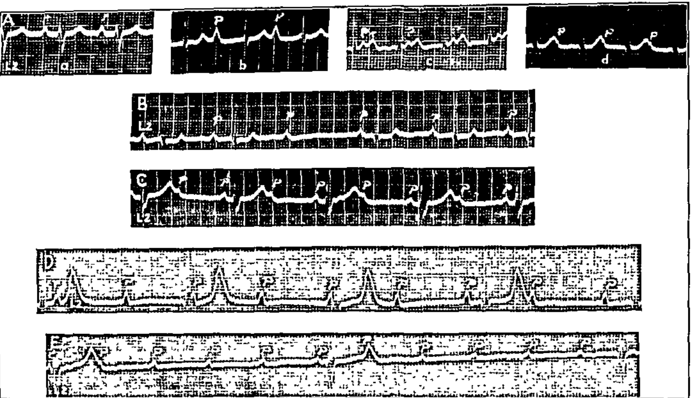


FIGURE 18 AV heart block *A* shows various types of grades of PR interval prolongation. *a* Shows PR intervals of 0 20 second; *b* shows PR intervals of 0 40 second, *c*, the P waves are situated between the QRS complexes and the T waves, the PR interval measures 0 44 second, *d*, the P wave is very small and superimposed on the T wave *B* shows a partial AV heart block with prolonged PR intervals, measuring 0.30 second In the second cycle, there is seen a dropped ventricular beat, an auricular wave with no ventricular response Note that the PR interval preceding the next ventricular cycle is shorter than the others. The AV node conducts more efficiently as a result of the longer rest period *C* shows partial AV heart block with 2.1 AV response (2.1 AV heart block) The auricular rate is 100 per minute, and the ventricular rate, 50 per minute Note that the PR interval preceding each QRS complex is exactly the same length *D* shows complete AV heart block The ventricular rate is 30 per minute The ventricular response is quite regular The auricular rate is 68 per minute, and the rhythm, regular. The ventricular and the auricular rhythms are entirely independent of each other No R waves are responses to preceding P waves, hence, the PR intervals are not related and these intervals vary in length *E* (from the same patient). The auricular rate is 88 per minute, but the ventricular rate is only 16 per minute

However, both types may depend on reversible changes that do not produce visible pathologic lesions and can be transient phenomena. This is particularly true of partial block which is produced transiently by such conditions as rheumatic fever, asphyxial conditions, by digitalis and vagal overactivity. Both partial and complete AV block are also seen transiently as a complication of occlusion of the right coronary artery. Syphilis is very rarely an etiologic factor in AV heart block.

Partial AV Block (Fig. 18 *A*, *B* and *C*): When there is only delayed AV conduction, it is practically impossible to recognize this clinically. The only possible clues lie in the facts that the first heart sound may be diminished in intensity, and, at favorable rates, a summation gallop may be detected by auscultation.[43] However, this condition is recognized easily by the electrocardiogram, which clearly shows long PR intervals This interval normally should not exceed 0.2 second.

When partial block produces dropped beats, clinical recognition is generally possible However, a 2:1 AV block may be mistaken for a slow sinus bradycardia and the pause produced by a dropped beat may be confused with the compensatory pause of a ventricular extrasystole. The electrocardiograph plainly reveals this condition by showing regularly recurring, normally shaped P waves with an occasional one failing to be followed by a ventricular response (Fig. 18 *B*).

Complete AV Block: Although instances are known in which complete block has existed for twenty years or more, these are rare and the condition is to be regarded as a serious disturbance in which the prognosis is definitely poor This is so because the disturbance predisposes to ventricular standstill or ventricular fibrillation, both of which may quickly cause death. These will be discussed under Stokes-Adams seizures.

The diagnosis usually can be made clinically by the slow and regular ventricular rate which is a result of the initiation of impulses by an idioventricular center at a rate usually around 40 per minute. The new idioventricular center is below the point of block and probably in the AV node or bundle of His. The chief therapeutic attack is directed toward preventing this idioventricular center from failing or toward increasing its rate of impulse formation. Neither of these effects can always be accomplished with certainty, but epinephrine, ephedrine, paredrine and typhoid vaccine[103] may at times be effective.

The electrocardiographic diagnosis is easily made. The ventricular complexes occur regularly and slowly. While the ventricular rate is usually slow, 30 to 40 per minute, it may be higher (60 per minute) in complete heart block, owing to digitalis, and in emergence from Stokes-Adams seizures, where it may be 100 per minute The auricular complexes are entirely independent and usually occur regularly at a normal rate (Fig. 18 *D* and *E*). It is to be borne in mind that there is no reason why complete AV block cannot exist in the presence of an abnormal auricular mechanism. One occasionally, therefore, sees complete AV block when the auricles are fibrillating, fluttering or beating very rapidly.[44]

The ventricular complexes are generally normal in duration and in contour. At times, they are widened and notched because of coexistent bundle-branch block.

Auriculoventricular Nodal Rhythm (Fig. 19)

According to the conception that is generally held, all heart muscle possesses certain fundamental properties, among which are excitability and rhythmicity. In the sinoauricular node, the property of rhythmicity is more highly developed than in any other portion of the heart muscle; hence it is the pacemaker of the heart. However, the AV node possesses the property of rhythmicity in only slightly less degree and readily takes up the role of pacemaker if either of the following two developments takes place: (1) the rhythmicity of the SA node becomes depressed to a level lower than that inherent in the AV node; or (2) the rhythmicity of the AV node becomes heightened to a point above that of the SA node Since the natural rate of the rhythmicity of the AV node is around 40 to 50 per minute, the former development (1) results in a slow heart rate and may be called the slow type of nodal rhythm, while the latter (2) produces a rate more rapid than the usual sinus rate and can be referred to as the rapid type of nodal rhythm.

Neither type is very common, but the slow form is seen much more often than the rapid. Both forms of AV nodal rhythm are nearly always temporary disturbances, only a few instance have been reported where the disturbance approached permanency. Among the causes are digitalis poisoning, acute rheumatic fever, and arteriosclerosis of the coronary arteries with resulting degenerative changes in the sinoauricular node. In certain patients it occurs during certain phases of respiration, after carotid sinus pressure and atropine administration.

The term "AV nodal rhythm" is usually applied when the impulses arising in the AV node, either slowly or rapidly, spread both downward to the ventricles and upward to the auricles, and thus control both chambers. This is not always the case, however, for frequently the nodal impulses go only to the ventricles, the auricles remaining under control of the sinoauricular node. When this is the case, some other name (ventricular escape) is given to the disturbance.

In considering the electrocardiographic diagnosis of AV nodal rhythm, it should be pointed out that the AV node is a relatively long structure—so much so that the electrocardiographic findings differ, depending upon whether the impulses arise in the head or auricular end, in the tail or ventricular end, or in the center. What usually is seen is a migration of the center of impulse formation, with some impulses arising from one situation in the node and some from another. Regardless of which center is active, there is one common feature: The auricular P waves are inverted or at least different in shape from P waves originating in the sinus node. This is so because an impulse arising in the AV node follows a course through the auricular muscle entirely different from the course of an impulse arising in the sinus node. The QRS complexes are usually supraventricular; that is to say, of normal width and shape, though occasionally one sees a slight aberration in their shape.

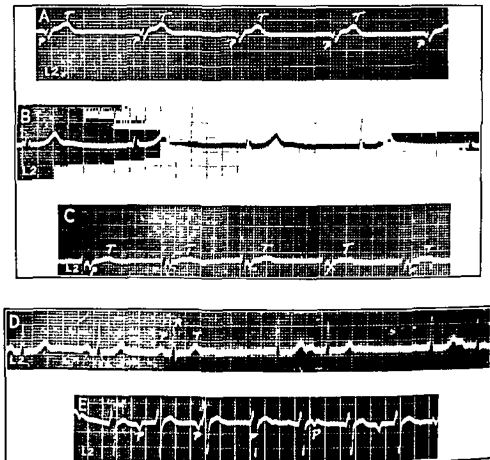


FIGURE 19 Auriculoventricular nodal rhythm and ventricular escape: *A*, *B* and *C* show different examples of the slow form of nodal rhythm *A*, The ventricular rate is 50 per minute Note the extremely short PR intervals (0 06 second) and the inverted P waves The center of impulse formation is in the upper portion of the AV node *B*, *The ventricular rate is 43 per minute. The P waves occur* synchronously with the QRS complexes, and therefore are not visible. The impulse probably arises from the middle portion of the AV node and spreads simultaneously to the auricles and the ventricles. *C*, The ventricular rate is 50 per minute The P waves are inverted and occur between the QRS complexes and the T waves The impulse arises from the lower portion of the AV node, and reaches the ventricles slightly before the auricles *D* and *E* illustrate two forms of ventricular escape. In *D*, the first three cycles are normal. The interval between the third and the fourth P waves is exactly twice the usual PP interval (sinoauricular heart block) As a result of the much delayed auricular impulse, the AV node "escapes" and initiates an impulse which goes forward to the ventricles (fourth and sixth ventricular complexes), but not to the auricles, the latter remaining under the control of the sinoauricular node. Two instances of such ventricular escape are observed in this record. In *E*, the P waves occur regularly and at a normal rate The ventricles are beating independently of, and more rapidly than, the auricles. This type of AV dissociation develops when some influence raises the rate of rhythmicity of the AV node above that of the sinoauricular node The rapidly formed AV nodal impulse in this instance goes forward to the ventricles but not backward to the auricles The P waves are, therefore, seen to occur regularly but have no relation to the following ventricular complexes

When an impulse arises in the ventricular end of the node, it has a much shorter distance to go to reach the ventricle than the auricles. As a consequence the ventricles are activated and contract before the auricles, with the result that the inverted P waves are usually situated between the QRS complex and the T wave (Fig. 19 *C*).

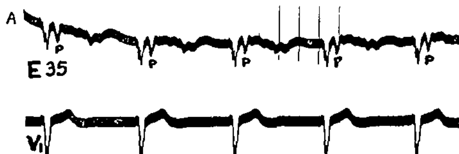


FIGURE 20 Esophageal leads *A*, Lower nodal rhythm Note the inverted P wave following the QRS complex in the unipolar esophageal lead 35 cm from the nares Lead V_1, recorded simultaneously, shows no evidence of atrial activity *B*, Localized posterior myocardial infarct

When an impulse arises in the auricular end of the node, the distance to be traversed to reach the auricles is short and the auricles beat before the ventricles. However, as the impulse is spreading from its point of origin upward toward the auricles, it is also spreading toward the ventricle, with the result that when the impulse reaches the auricle and the P wave begins to be written, the impulse will by then be well on its way through the node toward the ventricles. This naturally results in the PR intervals being quite short (Fig. 19 *A*).

With slow nodal rhythm, this variety with short PR intervals can be recognized unmistakably. With rapid nodal rhythm, it may be confused with auricular paroxysmal tachycardia The distinguishing point is the short PR interval of nodal rhythm, this interval will not be materially shortened in extrasystolic disturbances.

When the impulse arises around the center of the node, it may reach the auricles and ventricles simultaneously, with the result that the QRS and P waves occur simultaneously and the latter are invisible. When this is the case, the diagnosis is sometimes uncertain and must be arrived at largely through elimination. If one takes enough tracings, usually a cycle or cycles will be found in which the P wave shows; for, as we have already stated, the center of impulse formation in the AV node generally moves and rarely remains fixed (Fig. 19 *B*).

Coronary Sinus Rhythm (Supranodal Rhythm): The electrocardiographic pattern of coronary sinus rhythm is quite similar to that of upper nodal rhythm with the exception that the PR interval is within the normal range The following characteristics are suggestive of coronary sinus rhythm: (1) low amplitude P waves in Lead I; (2) inverted P waves in Leads II and III and inverted P waves in the precordial leads; (3) the PR interval measures 0.10 to 0.17 second. The significance of

this electrocardiographic pattern is probably similar to that of upper nodal rhythm. This pattern is observed in the presence of rheumatic carditis, digitalis effects and overactive vagal tone.

AV Nodal Extrasystoles and Nodal Paroxysmal Tachycardia: A nodal extrasystole is simply a single cycle of rapid type nodal rhythm. That is to say, for one cycle the rhythmicity of the AV node is raised to a higher level than that of the SA node. The electrocardiographic features are those that we have already described: The P waves will be inverted and will be either before, behind or buried in the QRS complexes. If before the QRS complexes, the PR interval will be shortened.

If instead of a single isolated nodal extrasystole there occurs a series of these beats, this constitutes nodal paroxysmal tachycardia. As the name implies, it is paroxysmal and the rate may rise as high as 140 to 160 per minute. This disturbance is the typical example of the rapid type of nodal rhythm but is quite rare.

Nodal Escape: We are using this term to apply to those instances in which impulses arising in the AV node go forward and control the ventricle but do not reach the auricles, the latter remaining under control of the sinoauricular node. The factors that produce this disturbance and the forms in which it manifests itself (slow and rapid) are those already discussed. There is that type in which the rate of rhythmicity of the sinus node becomes depressed to the point that the normal stimulation of ventricular contraction by the auricular impulse is so delayed that the inherent rhythmicity of the AV node asserts itself and produces a stimulus. This is precisely the mechanism at work in the slow type of nodal rhythm, except that the nodal impulse in nodal escape affects only the ventricles and not the auricles. This slow type of escape is often confined to a single cycle; frequently an exaggerated sinus arrhythmia will bring it into play. It may be present, however, for a number of cycles.

This can be easily recognized in the electrocardiogram by the fact that the escaped ventricular complexes are not preceded by P waves. The latter can usually be seen, at least partially, behind the QRS complexes, and can be seen to be normally upright and therefore of sinus origin (Fig. 19 *D*).

The mechanism of the other variety of nodal escape is that of rapid nodal rhythm; the rate of rhythmicity of the AV node is raised above that of the sinus node. If the nodal impulses thus resulting can go forward but cannot go backward through the node, the ventricles are controlled by these impulses but the auricles continue to beat in response to sinus impulses. We have, therefore, an AV dissociation with the ventricles beating more rapidly than the auricles (Fig. 19 *E*).

In the electrocardiogram this is plainly seen. The ventricular beats are of normal shape, but are not preceded by P waves at a consistent PR interval. The ventricular complexes are regular in rhythm and are all responses to nodal impulses, except that an occasional beat may be out of rhythm because it is a response to an auricular and not a nodal impulse. This can happen when the auricular impulse finds the refractory state of the AV node and ventricles favorable. The P waves are normally

upright and regular and occur at a slower rate than the ventricular complexes.

Ventricular Extrasystoles

There is considerable evidence to suggest that the mechanism of ventricular extrasystoles is not a simple one. Since the matter is not entirely clear, we will refer only to the older view and not discuss the parasystolic

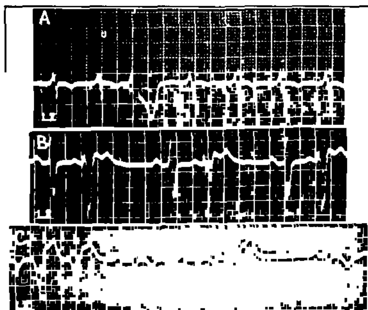


FIGURE 21. Extrasystoles. [illegible]
T [illegible]
A [illegible]
ve [illegible]
C [illegible]

theory of extrasystoles (see Fig. 22 *A*, *B*, and *C*). Ventricular extrasystoles are generally considered to be the result of a stimulus to contraction arising at some place in the ventricular muscle. Ventricular beats produced by this mechanism are always premature and since the impulse arises in the muscle of one ventricle, this chamber will be activated before its fellow, with the result that the two ventricles act asynchronously. This produces ventricular complexes which are slurred, widened and of considerable voltage. The T waves are also large and opposite to the direction of the QRS complexes. Widening and notching of the premature ventricular complexes is not sufficient for diagnosis; it must be further shown that these complexes are not preceded by P waves. It is upon these features that the electrocardiographic diagnosis is made.

Ventricular premature contractions may appear in the form of isolated beats; they may be numerous, arise from one or many foci, or occur in pairs or short runs of three or more beats, thereby constituting a potential ventricular tachycardia. A very interesting variety is that in which

ventricular extrasystoles are coupled to preceding normal complexes in the sense that the time interval between the extrasystole and the preceding normal complex is the same from cycle to cycle (Fig. 21 *B*). The chief clinical importance of this disturbance lies in the fact that it is frequently produced by overdigitalization. Theoretically, ventricular extrasystoles are of interest because they suggest the possibility that the mechanism back of extrasystoles may be a form of the re-entrance phenomenon and may, therefore, be close to the circus movement that produces auricular fibrillation and flutter.

Ventricular extrasystoles occurring late in diastole give rise to an effective ventricular contraction which produces a radial pulse. Occurring early in diastole, the intraventricular pressure may be too small, as a result of insufficient ventricular filling, to yield a pulse at the wrist. A pulse deficit may therefore occur in the presence of numerous ventricular premature beats.

The auricular mechanism is not disturbed by ventricular extrasystoles; P waves continue to be formed rhythmically. This gives rise to one of the outstanding clinical phenomena: the compensatory pause. The P wave that occurs during or just after the premature ventricular beat cannot secure a ventricular response, for it occurs during the refractory period of the ventricle. The first ventricular contraction after the premature beat will be a response to the next rhythmic P wave. The interval between the premature beat and the next ventricular beat is therefore longer than the usual RR interval and is referred to as the compensatory pause.

However, if the premature beat occurs sufficiently early in diastole at a relatively slow ventricular rate (*e. g.*, 60 per minute), ventricular recovery may have proceeded to such an extent that every rhythmic P wave secures a normal ventricular response and no compensatory pause occurs. Such extrasystoles are referred to as interpolated.

Ventricular extrasystoles may arise in the right ventricle, the left ventricle, or the interventricular septum. The point of origin may be determined by the direction of the extrasystoles in Leads I and III. If upright in Lead I and down in Lead III, they are probably right ventricular; if down in Lead I and upright in Lead III, they are probably left ventricular.[28]

Since this disturbance is a very common one, its clinical significance is important. Undoubtedly, ventricular extrasystoles occur as the result of myocardial diseases of various types. But they also occur frequently in individuals with normal hearts. Their importance, therefore, is to be evaluated by clinical study; alone they warrant no diagnosis of disease. In most instances, they can be abolished by any factor that increases the cardiac rate, *e. g.*, emotion, exercise or atropine. In some cases where they occur in association with myocardial disease, exercise tends to increase them by putting a greater load on an already overburdened heart muscle.

Ventricular Paroxysmal Tachycardia

Ventricular paroxysmal tachycardia (Fig. 22) generally is considered to be a disturbance consisting of a series of ventricular extrasystoles The ventricular rate usually ranges from 150 to 170 per minute. The diagnosis can be made with certainty only by electrocardiographic study. The criteria for electrocardiographic diagnosis of ventricular tachycardia were established by Robinson and Herrmann.[46] The beats of the paroxysms should be ventricular in type in the sense that they are widened and

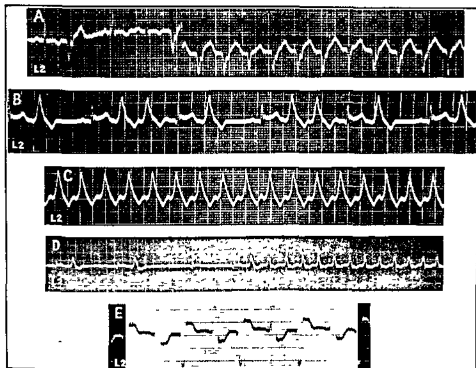


FIGURE 22 Ventricular paroxysmal tachycardia The first portion of strip *A* shows periods of normal rhythm interrupted by an occasional ventricular extrasystole In the rest of the strip, there is a paroxysm of ventricular tachycardia (*ventricular rate, 154 per minute) Note that the ectopic beats of the paroxysm* are identical in shape with those of the isolated ventricular extrasystoles Normally shaped P waves continue to occur regularly at a much slower rate (115 per minute), and independently of the ventricular complexes *B* and *C* are from the same case of ventricular tachycardia occurring during acute pericarditis In *B* are shown isolated ventricular extrasystoles, some of which are occurring in pairs *C* shows a continuous ventricular tachycardia Note that the ectopic beats are identical in shape with the isolated ventricular extrasystoles observed during the normal rhythm The ventricular rate during the paroxysm is 160 per minute *D*, Ventricular paroxysmal tachycardia, occurring during auricular fibrillation. Note the normal ventricular complexes followed by coupled ventricular extrasystoles During the paroxysms, the shape of the ventricular complexes is the same as that of the isolated extrasystoles Note also that the initial beat of the [illegible]

notched. If auricular fibrillation exists, it is essential for the diagnosis that tracings be obtained when the ventricular paroxysm is not present and that these tracings show isolated ventricular extrasystoles—preferably those which are coupled to preceding normal beats (Fig. 22 *D*). The diagnosis can be established if the ventricular complexes of the paroxysm are identical with the isolated ventricular extrasystoles. It is even more fully established if the first beat of the paroxysm is coupled to the preceding normal complex by the same time interval that exists between an isolated extrasystole and its preceding normal beat. If auricular fibrillation is not present, the diagnosis is established if the ventricular complexes are widened and notched and occur more rapidly than, and independent of, the normally shaped P wave. The ventricular rate may be perfectly regular but generally is slightly irregular. It has been proposed that this slight irregularity, together with the variation in the intensity of the first sound which is often present, may suggest this arrhythmia clinically.[47]

This arrhythmia is of great prognostic significance since its duration for any period of time predisposes to ventricular fibrillation, a condition usually incompatible with life. It occurs in the presence of severe myocardial disease, particularly as a complication of acute or subacute coronary occlusion and as the result of toxic digitalis effects.

The complexes of ventricular tachycardia are usually unidirectional. Occasionally, they are bidirectional (Fig. 22 *E*); this is probably a more serious type and is, in our experience, almost always a result of toxic digitalis action. From theoretical considerations, this type has been said to be due to a circus movement in the ventricle and has been called ventricular flutter analogous in mechanism to auricular flutter.

Two other types of ventricular tachycardia are sometimes observed. When present, they usually produce Stokes-Adams seizures. The first, producing minor attacks, consists of markedly aberrant widened QRS complexes (Fig. 23 *A*); they differ from the usual type observed in ventricular tachycardia in that the rate is more rapid (200 to 230 per minute) and the amplitude of the QRS greater (Fig. 23 *A*). The second type produces major seizures. The complexes show greater widening and are more bizarre. The waves consist of more or less regular helixlike undulations which usually precede true ventricular fibrillation (Fig. 23 *B*). Both of these variations have been referred to as prefibrillatory types of ventricular tachycardia, and more recently, with better justification, the term "ventricular flutter" has been applied to the prefibrillatory type of ventricular tachycardia (Fig. 22 *B*—first part of strip).

T-Wave Changes Following Paroxysmal Tachycardia: Following attacks of paroxysmal tachycardia, particularly those of long duration in older individuals and in those with pre-existing heart disease, the electrocardiographic pattern shows inverted T waves which resemble those seen in the subacute stage of myocardial infarction. Such findings often present a problem in differential diagnosis, since patients, during the paroxysm, may also have precordial pain. These changes are the result of prolonged coronary insufficiency; areas of focal necrosis have been

observed in the ventricles as the result of the coronary insufficiency. In several fatal cases of long-lasting tachycardia, diffuse myocardial fibrosis has been found at autopsy. The return of the electrocardiographic changes to normal often takes many days or weeks. One should rule out the cardiac effects of digitalis and quinidine as productive of these changes.

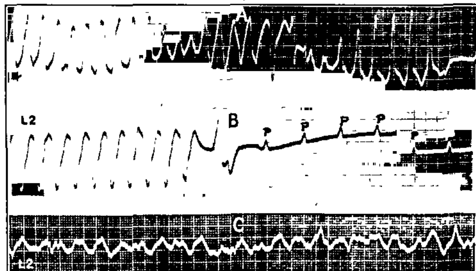


FIGURE 23. Ventricular fibrillation: Strips *A*, *B*, and *C* were obtained during a Stokes-Adams attack in a patient with complete AV heart block Strip *A* shows the prefibrillary type of ventricular tachycardia Note the markedly aberrant type of ventricular complexes with a rate of 200 per minute. These very frequently precede the development of ventricular fibrillation or complete ventricular standstill. *B* shows the typical prefibrillary type of ventricular tachycardia (rate, 200 per minute). This ends suddenly and is followed by a period of ventricular standstill. During the ventricular disturbance the auricles continued to beat at a rate of 88 per minute *C* shows ventricular fibrillation Note the extremely irregular aberrant type of ventricular response The patient recovered from this paroxysm

Ventricular Fibrillation

Ventricular fibrillation (Fig. 23 *C*) is the most serious of the arrhythmias; its presence for even a brief instant is usually incompatible with life, though there are on record a few instances in which recovery has occurred after ventricular fibrillation had existed for several minutes. This arrhythmia is probably a frequent terminal event in many patients. It is probably the mechanism by which death occurs in coronary occlusion, digitalis poisoning, and in some Stokes-Adams attacks. It is usually preceded by attacks of ventricular tachycardia

The cardiac mechanism during these seizures may be more easily followed in animals, where they can be induced by electric shock, by coronary occlusion, or by toxic amounts of digitalis. With the onset of ventricular fibrillation, the blood pressure drops to zero or practically so; a series of rapid irregular undulations replace the coordinated contraction of the ventricle. These oscillations become gradually less marked until they cease altogether.

The graphic records show bizarre ventricular oscillations without suggestion of a QRS or T wave. The waves are often very coarse and irregular and are accompanied by wide movement of the string. Auricular contractions may nevertheless be present. Records of onsets during Stokes-Adams seizures in complete AV block show that this arrhythmia is usually preceded by ventricular tachycardia, especially of the prefibrillatory type, and may begin suddenly following a period of ventricular standstill.[48] Recorded endings have shown the gradual appearance of ventricular beats, at first markedly aberrant, later less so. The idioventricular beats gradually resume their usual contour and rate.

In animals, such seizures induced by electric shock have been terminated, and normal rhythm restored, by application of potassium followed by calcium salts and by electric countershock.[14,99] So far, few such attempts to accomplish this in the human subject have been made.

Pulsus Alternans

Pulsus alternans is characterized by rhythmic occurrence of a strong beat followed by a weak beat. The resulting pulse waves alternate in strength. The ventricular rate is quite regular. The pulse rate, however, may be slightly irregular owing to a variation in sphygmic intervals as a result of variation in ventricular ejection. Alternation may involve the auricle, both ventricles, or only the right or left ventricle; it has been observed even in the presence of auricular fibrillation This condition may be detected at times by palpation of the radial pulse. It is, however, more accurately determined by the use of the blood pressure cuff, which may indicate variations in the systolic pressure in alternate cycles of from 12 to 30 mm., or by graphic registration of the brachial or radial pulse. Occasionally, alternation of the heart sounds may be recorded at the apex. One must be careful to exclude the presence of coupled rhythm; in this condition, the apical rate is irregular.

Alternation is generally the result of a profound cardiac disturbance. However, when it is present only with very rapid rates, it is not nearly so significant. It is not uncommon during rapid paroxysmal tachycardia; the alternation disappears as the rate is slowed.

There are two main theories underlying alternation: (1) that all the fibers contract during one cardiac cycle, but owing to diminished excitability some fibers do not contract in the next cycle[49]; and (2) that separate groups of fibers fail with alternate beats.[50]

Evidence of alternation may be present in the electrocardiogram (electrical alternation). This may occur together with or be independent of mechanical alternation; its significance, however, is the same. The electrocardiogram may indicate alternation in the height of the QRS complexes (Fig. 14), alternation in the length of the PR interval and alternation in the amplitude of the T waves in indirect and/or precordial leads.[104,105,106]

INTRACARDIAC ELECTROCARDIOGRAPHY

As a result of the increased use of the catheterization technic, study of the intracardiac potentials in animals and man has added much to the understanding of electrocardiography.[52-56] This method has been of particular

value in correlating various deflections in normal and abnormal states with activation of various portions of the auricles and ventricles Thus, intracardiac leads have given information relative to the conduction of the normal impulse in the auricle and ventricle, and concerning conduction of the cardiac impulse in auricular ectopic rhythms as well as in right and left ventricular hypertrophy and in right and left bundle-branch block.

Right auricular, right ventricular and pulmonary-artery leads are easily obtained by attaching an electrode to the cardiac catheter and connecting it and an indifferent electrode to the galvanometer. Left ventricular and auricular intracardiac leads are not so easily obtained, since introduction of a catheter into the left ventricle is considered a dangerous procedure. The catheter may encroach upon the openings of the coronary arteries, may injure the aortic valves, and—in the attempt to enter the left auricle—may injure the chordae tendineae and the mitral valve. Zimmerman and Scott[51] have recorded left ventricular potentials in humans by inserting a catheter through the brachial artery into the aorta and left ventricular cavity. Left endocardial leads have been obtained by direct puncture of the ventricular wall or by arterial catheter in normal animals and in animals in which right and left bundle-branch block had been induced previously.

Right Auricular Cavity Potentials: When one follows the course of depolarization and repolarization of the heart with reference to the position of the recording electrode, the various deflections of the intracardiac electrocardiogram can be predicted and explained. If the exploring electrode is placed at or above the sinoauricular node in the right auricle, the impulse stimulating the auricle must of necessity proceed away from the electrode, and a negative deflection is recorded. When the impulse has reached all of the auricular muscle, the peak of the negative deflection has been reached and it returns to the base line. If no ventricular complex interferes, repolarization currents are then recorded in the form of an auricular T wave. This will be opposite in direction to the P wave, since in the auricle depolarization and repolarization proceed in the same direction. Usually, however, as soon as the galvanometer has returned to the base line, the AV node discharges its impulse, which travels down through the bundles and into the ventricular muscle, again in a direction away from the electrode, and therefore a predominantly negative QRS deflection is recorded. Repolarization, when its proceeds in the same direction as depolarization, will inscribe a deflection which is opposite in sign to that produced by depolarization When it proceeds in a direction opposite to that of depolarization, it records a wave of the same sign. Repolarization currents of the ventricle proceed in opposite direction to those produced by depolarization, and therefore a negative deflection (ventricular T wave) is inscribed in an intra-auricular lead.

If the exploring electrode is still in the auricle, but below the point of origin of the auricular stimulus, depolarization first passes toward it, then comes abreast, and finally goes beyond it. It becomes immediately apparent that under these circumstances the first deflection of the auricular wave is upright, immediately followed by a downward deflection. When the electrode is at or below the AV groove, the auricular impulse travels toward

the electrode during the entire period of auricular depolarization, and the complex is upright throughout. Because of the proximity to the origin of the currents, it is also tall and peaked.

It has been shown by Hecht[54] and Levine and associates[54] that the auricular complex of the electrocardiogram is predominantly a downward

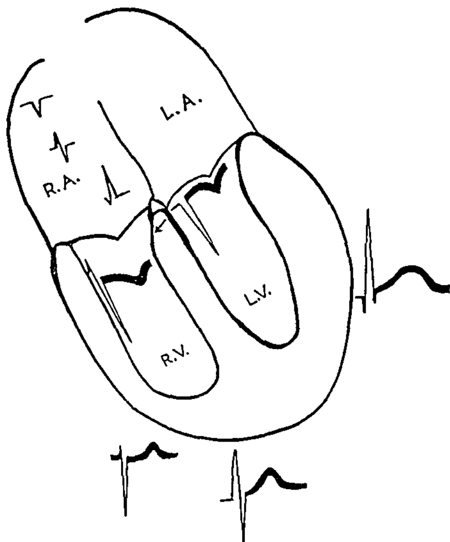


FIGURE 24 Normal heart, showing the configuration of auricular and ventricular complexes at various points in the right auricle and in the cavity of the left and right ventricles; comparison with epicardial leads on the right side of the precordium, the transitional zone, and the left side of the precordium.

deflection when recorded high in the right atrium (PQS),* biphasic when recorded in its middle portion (PRS), and predominantly upright when recorded low in the right atrium (PR). The time of inscription of the intrinsic deflection becomes later as the electrode is moved to lower positions

* To distinguish the QRS complexes of the auricle from those of the ventricle, it has been suggested that the auricular potential be described by letters in small capitals, e g, QS, QRS.

in the atrium (median values· 0.00 sec. [high], 0.02-0.03 sec. [mid-position], 0.05 sec. [low]). Intrinsic auricular deflections were often absent in tracings made in the low median position, presumably because of absence of auricular muscle mass at this point. Auricular premature beats were occasionally recorded. They began with sharp downward deflection, evidently indicating that the impulse retreated from the electrode and presumably was initiated by it Since the intrinsic deflection arrived at esophageal electrodes 0.05 sec. later than at an intra-auricular electrode placed at the same vertical level, it was concluded that the left atrium is stimulated later than the right.

In right ventricular hypertrophy, intracavity leads placed in the right auricle show that the auricular complex is not modified Further, the ventricular complexes are of qR or qRs types. The "late" R increases in voltage, and it is for this reason that we relate it to the late activity of some hypertrophied muscular portions of the right ventricle. In left ventricular hypertrophy the auricular complex is not modified. The ventricular complex is similar at all auricular levels and is QS or QrS in type. The diminution or absence of the late R is thought to be due to the strong vector forces representing the activity of the hypertrophied free wall of the left ventricle. In right bundle-branch block the "late" R in tracings made at high auricular levels is very wide and bizarre and very similar to that seen in Lead VR or aVR in the same type of block. The tracing is of the qR type. In tracings made at lower auricular levels the complex is qRs in type with negative T wave. In left bundle-branch block the ventricular complexes obtained from inside the auricle have only negative deflections (QS) with positive T waves.

Right Ventricular Cavity Potential: The configuration of the QRS complex in unipolar leads (endocavity, precordial and unipolar limb leads) is influenced by the following factors: (1) Placement of electrode with reference to the depolarization process; (2) direction of activation with respect to the position of the electrode; (3) time and order of depolarizing with respect to the exploring electrode (*e. g*, the early ventricular depolarization activation of the septum from left to right will not be neutralized by other potentials because no others are present for that brief period of time; the same is true of potentials produced at the end of the depolarization process); if two currents flow simultaneously in opposite directions they will be partially or entirely neutralized; (4) the potential is much greater in the left ventricle than in the right because of its greater muscle mass.

It has been mentioned previously that the first ventricular activation is the stimulation of the interventricular septum from left to right. In the right ventricle, therefore, a small upward deflection is recorded at this time; in the left ventricle there is a downstroke. This isolated deflection is very brief and is quickly succeeded by the passage of the impulse through the walls of the right and left ventricles. The wave of activation spreads from endocardium to epicardium (therefore away from the electrode), and the initial upstroke is immediately followed by a deep downward deflection (rS).

The upstroke is small because the depolarization process is brief and the course traversed in the septum is short; the succeeding deflection S is downward because depolarization on the left side of the interventricular septum and left ventricle proceeds in a direction away from the exploring electrode. The amplitude of the S wave is much greater than that of the

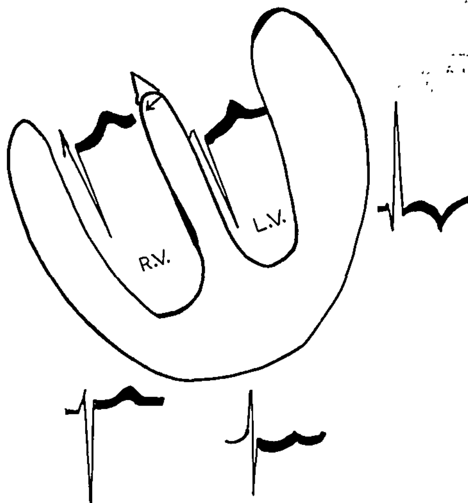


FIGURE 25 Left ventricular hypertrophy, showing endocardial and epicardial potentials

initial R wave because of the great mass of left ventricular muscle to be activated as compared to that involved by the small R wave. The resulting deflection is of the rS type (Fig. 24). This deflection varies somewhat, depending on the placement of the endocardial electrode. Occasionally it may be of the QS or RS or rSr′ type

In left bundle-branch block, the downward deflection is notched and widened in the intracavity lead from the right ventricle, because of the delay of the currents flowing away from the electrode (Fig. 28).

In the normal heart, repolarization takes place in a direction opposite to that of depolarization. Since the major deflection in the endocardial electrocardiogram is down, the T wave is inverted also (Fig. 24).

In the normal heart left endoventricular potential differs from the right only by the absent initial up-deflection owing to the direction of the initial septal activation. In high left bundle-branch block, a left ventricular cavity lead shows an initial upward deflection as the interventricular septum is activated anomalously from the right to left, and then a downward deflection as the impulse spreads through the left ventricle toward the epicardium (rS) (Fig. 28).

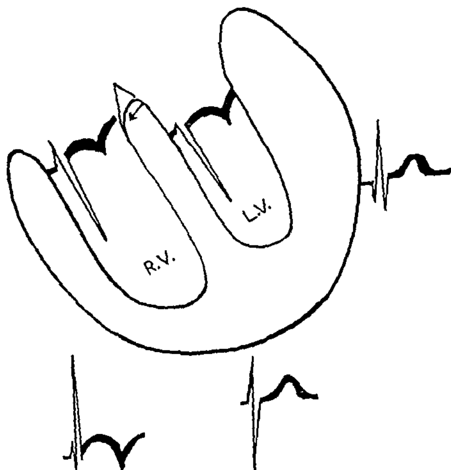


FIGURE 26 *Right ventricular hypertrophy, showing endocardial and epicardial potentials (see page 1325).*

These observations are borne out by the studies of Battro and Bidoggia,[52] Sodi-Pallares and his associates,[53,56] Levine and others.[54] They showed that the ventricular complex in the normal right ventricular cavity has an initial positive deflection, followed by a negative deflection of great amplitude and second inconstant upward wave (rS or rSr'). The T wave is definitely negative, sharp and deep In right or left ventricular hypertrophy, tracings taken from the right ventricular cavity do not differ from the normal intracavity pattern. *In high left bundle-branch block the right* endoventricular leads show no initial positive wave and the complex con-

sists of a simple QS (since the septum is no longer activated from left to right). In right bundle-branch block the initial upward deflection is followed by a downward deflection which is of larger amplitude than normal and notched (Fig. 27).

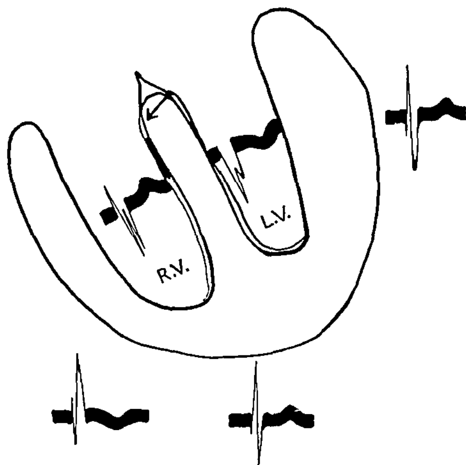


FIGURE 27. Right bundle-branch block, showing endocardial and epicardial potentials (see pages 1286 and 1330).

Sodi-Pallares and his associates[56] made further studies of the intracavity potential changes in right bundle-branch block. They state that there is no reason to believe that right bundle-branch block alters the early left to right activation of the upper portion of the septum. Therefore, the electrocardiographic findings in the early portions of electrical systole are the same as those found in normal subjects and are not modified by the presence of the block. However, a later phase, which appears 0.04 to 0.05 second after the beginning of the QRS, and which consists of an R'S', appears in right intracavity tracings coincidently with the first portion of the ascending branch of R' in Lead V_1. They believe that these multiphasic complexes record two phases of septal activation produced above and below the site of block.

The following sequence of activation (which is correlated with the rsR'S') occurs: Initial small r is upright and is produced by septal activa-

tion from left to right; s is due to activation of the upper left portion of the interventricular septum (away from the electrode); the tall R is due to (1) initial activation of the right side of the interventricular septum; and (2) terminal portion of R by activation of the free wall of the right ventricle or activation of the interventricular septum from left to right; the terminal S wave is the result of terminal left ventricular activation.

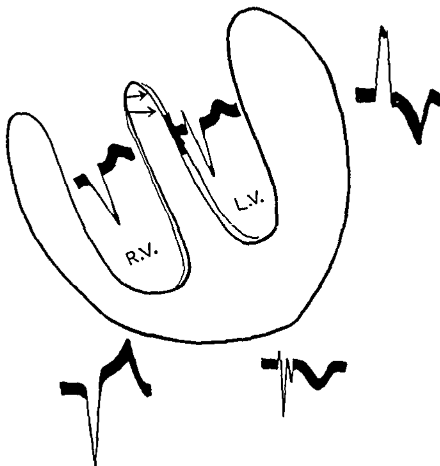


FIGURE 28. Left bundle-branch block, showing endocardial and epicardial potentials (see pages 1289 and 1328)

Left Ventricular Cavity Potential: The left endocardial potentials consist of the following patterns: A QS deflection followed by an inverted T wave is seen in normal hearts, in right ventricular hypertrophy and in the presence of right bundle-branch block. In these conditions the course of depolarization through the septum and from endo- to epicardium does not vary from the normal. The presence of an inverted T wave in these conditions has been discussed above. In left ventricular hypertrophy the QS pattern is still seen, but the T wave is often upright, since the repolarization is disturbed In high left bundle-branch block an RS pattern is seen (Fig. 28), since the initial depolarization of the interventricular septum now takes place from right to left. In low left bundle-branch block a QRS

may be seen, since above the block left to right stimulation of the septum takes place. This is then followed by right to left depolarization of the lower portion of the left half of the interventricular septum and finally by the stimulation of the free wall of the left ventricle from endo- to epicardium. In the presence of infarction of the right portion of the interventricular septum a QS deflection is again seen.

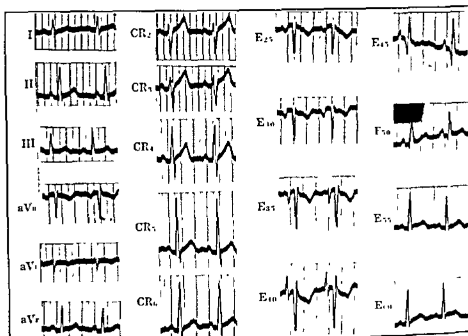


FIGURE 29 Normal tracing with normal esophageal leads at various levels E_{25} and E_{30} represent the supra-auricular level E_{40} represents the auricular level Note intrinsicoid deflection and PQRS E_{45} at the AV groove. E_{55} and E_{60} represent the normal ventricular level, the electrocardiogram of which is similar to CR_5

The Relation of Endocardial and Epicardial Potentials: When one compares the endocardial with the epicardial potentials, it must be remembered that an electrode will record the sum of all electrical influences acting at a given instant. Thus, in both V_2 and a right intraventricular lead, the spread of the auricular impulse is toward both of these electrodes and a positive P wave will be recorded. The initial spread of the impulse through the interventricular septum from left to right is directed toward both of these electrodes (in a normally positioned heart), and again the deflection is upright (r). As the impulse spreads from the endo- to the epicardium in the right and left ventricle, the potentials thus created in the left ventricle are greater and of longer duration than those in the right ventricle. Therefore, the endocardial lead will inscribe a deep negative deflection (S). V_2 will also inscribe a negative deflection, but one which is not as deep, since the endo- to epicardial potential of the right ventricle will act in a positive direction, while the potential differs from the epicardial lead of the same ventricle only when recording the activity of the free walls of the

heart. Similarly, if one puts an endocardial electrode in the left ventricle and a V lead on the left side of the precordium (*e. g.*, V_5), the P wave is again positive. The initial ventricular deflection is negative in both endo- and epicardial leads (initial q) since it is due to activity of the septum, the impulse proceeding from left to right. As the free walls are activated, the

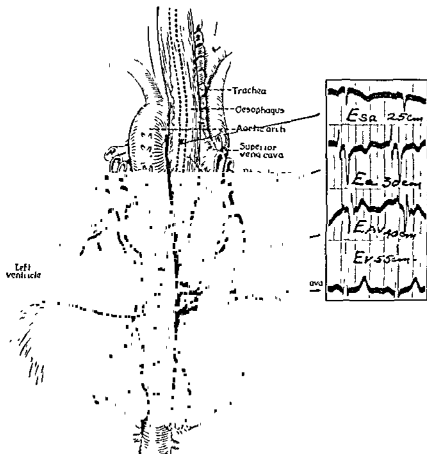


FIGURE 30 *Showing the relationship of the posterior aspect of the heart and the Levin tube in the esophagus to the anatomical structures at the various levels* and the resulting electrocardiograms obtained (after Brown: Am Heart J).

deflection of the endocardial lead continues downward to inscribe a deep negative deflection, while the potential over the precordium is positive, since the impulse spreads through the thick left ventricular wall toward the electrode [57]

The electrical potentials that produce RS-T segments and T waves are somewhat more complicated and difficult to explain. Thus, the endocardial T wave is normally negative. However, the precordial T wave over the right ventricle may also normally be negative. Over the left ventricle the T waves are normally opposite in sign in the endo- and epicardial leads.

ESOPHAGEAL LEADS

Esophageal leads were first described in 1906 by Cremer,[58] who was attracted to this method by the desirability of placing the exploring electrode closer to the cardiac electrical field. This method has recently been applied more extensively in electrocardiography by various investigators.

As the esophagus passes downward through the thorax, it courses along the right side of the arch of the aorta behind the trachea. In its downward course, it is in relation to the following portions of the posterior surface of the heart: the left auricle, the AV groove, and the posterior or basal portion of the left ventricle. It is thus clear that an electrode placed in the esophagus immediately adjacent to the heart is in a position to detect variations in electrical potential occurring in that organ which cannot be duplicated by any other semidirect lead in the living human subject. The proximity of the esophageal electrode to the source of the changes in electrical potential reduces the possible interference of a distal or indifferent electrode and there is no interposition of poorly conducting lung tissue between it and the heart.

The Normal Esophageal Leads: Esophageal leads may be taken by the use of a Levin tube, with a metal tip which is connected by a thin wire passing through the lumen of the tube to a binding post. The tube is calibrated for length, and the following distances from the incisor teeth are used to locate the various cardiac structures, which are fairly constant, and correlate them with the electrocardiographic patterns: The supra-auricular level is situated up to 25 cm.; auricular level, 30 to 40 cm.; AV level, 40 to 45 cm.; and ventricular level, 50 to 60 cm. Each one of these levels has a fairly definite electrocardiographic pattern, as shown in Figs. 29 and 30. The ventricular portions of the complex closely resemble aV_R when the esophageal electrode is over the atrium and aV_F when it is over the ventricle. A tracing made at the supra-auricular level shows QS complexes representing both auricular and ventricular potentials. A tracing made at the auricular level shows a PRS wave at the time of auricular depolarization, the peak of the PR being the beginning of the intrinsicoid deflection of the P wave; ventricular activation is inscribed as a QS complex; the AV groove level is characterized by an upright peaked P wave *and a QR pattern for ventricular conduction. The* ventricular level shows a moderate upright P, a small Q (less than 3 mm. in height), a tall R wave, followed by an upright T and resembles the ventricular complex in CR_4 or CR_5. The small Q wave is interpreted as evidence of the early activation from left to right of the interventricular septum.

Value of the Esophageal Leads: Esophageal leads are of value in the following respects: (1) By placing the electrode close to the auricle we obtain a more accurate configuration of the auricular complex and can observe the auricular T wave. (2) These leads clarify the diagnosis of various auricular arrhythmias which are obscure in the limb or precordial leads. (3) They may reveal infarction of the auricular muscle. (4) At the auricular level the ventricular complex which follows gives information relative to the endocardial infarction and digitalis effects. (5) At the ventricular level we obtain the best evidence of posterior myocardial infarction. (6)

Myers and Klein[59] used esophageal leads to correlate certain patterns of Leads aV_L and aV_F with the position of the heart and thus were able to explain some of the unusual patterns observed in these leads.

The Abnormal Esophageal Leads: Auricular fibrillation was studied by this method by Nyboer and Hamilton.[60] The fibrillation waves were

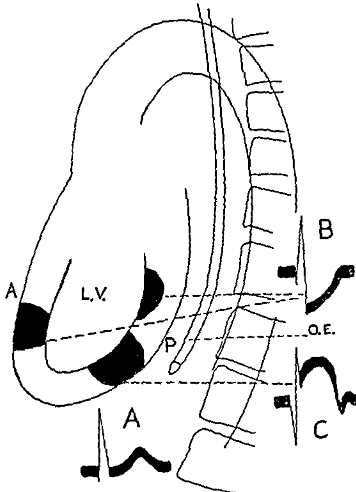


FIGURE 31. Diagrammatic representation of the heart, showing the effect of various types of infarctions on the ventricular complex of the esophageal electrocardiogram taken at the ventricular level *O.E.*, Esophageal lead *L.V.*, Left [illegible] lead at the ventricular [illegible] esence of either an [illegible] the posterior wall. [illegible] depressed *C*, Ventricular complex in esophageal lead, involving the posterior wall Note the deep Q with elevation of the RS-T segment

much easier to see by this means than by most of the others. In roughly half their cases a definite auricular intrinsicoid deflection could be demonstrated; in the other half, there were only irregular undulations of the base line. They could find no reason for the difference between these two types, nor did they respond differently to therapy.

Esophageal leads have made possible a significant advance in the knowledge of the Wolff-Parkinson-White syndrome. Rosenbaum and associates[61] were able to demonstrate rather conclusively that in this anomaly the posterior ventricular wall is activated prematurely, and together with the normally conducted impulse produces the aberration of the QRST complex characteristic of this condition.

The electrocardiographic findings of right ventricular hypertrophy have been studied by means of intracavity, esophageal and aV_R leads in man by Schlesinger and associates.[55] Except in one out of five patients the ventricular complexes of these three leads bore great similarity to each other. This is easily explained by the coincidence of the projection of the potentials tapped by the exploring electrode under these circumstances. One of the intracavity patterns differed from the aV_R and esophageal leads in this one case by inscribing a QR instead of essentially negative QRS complexes. This may probably be explained if one assumes apposition of the intracardiac electrode to the hypertrophied right ventricular wall, which is activated very late.

In myocardial infarction, the esophageal lead is the method of choice for localizing posterior and subendocardial involvement. The pathologic changes may be divided roughly into those occurring with the electrode at the auricular and those at the ventricular level. Thus, in anterior infarction the QRS is normal; the RS-T segment may be normal or depressed when the esophageal electrode is over the ventricle (Fig. 30). At the auricular level the RS-T segment is more often depressed. In posterior infarction there is a deep Q wave (over 4 mm.) at the ventricular level; and if the involvement is active, RS-T segment elevation and T wave inversion are observed (Fig. 31). The RS-T segment elevation persists at the auricular level usually, but the QRS may appear normal for this lead.[62]

T wave changes in esophageal leads recorded over the ventricle are roughly similar to those seen in the chest leads and are indicative of nonspecific damage or digitalis effects. The same may be said for the deflections recorded over the atrium except that it must be remembered that here the mirror image of the ventricular potentials recorded lower down is normal. Similarly, digitalis produces RS-T segment depression at the ventricular level and RS-T elevation with the electrode at the atrium.

UNIPOLAR LIMB LEADS

The application of unipolar limb leads to electrocardiography is based on certain assumptions, some of which are as yet controversial. It depends first on the acceptance of the Einthoven-triangle hypothesis in which it is assumed (1) that the heart is a dipole situated in the center of an equilateral triangle, (2) that the electrical potentials are transmitted through a homogeneous conducting medium, and (3) that the right arm, left arm and left leg are equidistant from the heart. None of these stipulations is actually true as far as the heart is concerned. The heart is situated not in the center of an equilateral triangle but closer to the left than to the right side. It is situated more anteriorly in the chest, and the conducting medium around the heart varies considerably in its ability to transmit the

cardiac potentials to the periphery; for example, the anterior chest wall is a relatively good conducting medium, the lungs relatively poor. Katz,[126] Wolferth, Livezy and Wood,[127] Groedel,[129] and others have presented many objections to the Einthoven theory. However, the proponents of this theory feel that while it is not mathematically perfect as applied to the human subject, it is sufficiently serviceable for practical purposes.

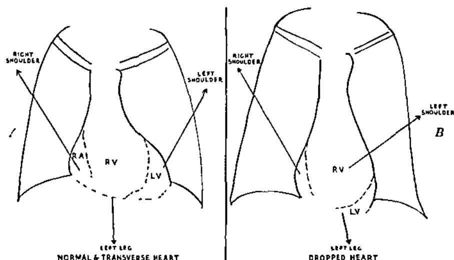


FIGURE 32 Diagrammatic representation of the heart, showing the relationship of the right ventricle and left ventricle to the anterior chest wall *A*, Normal and transversely placed heart Arrows indicate the transmission of the left ventricular potential to the left shoulder and the right ventricular potential chiefly to the left leg *B*, Heart in vertical position The left ventricle rests to a greater degree on the diaphragm, the left ventricular potential is transmitted to the left leg, and the right ventricular potential is now transmitted to the left shoulder The relative position of the right auricle to the right shoulder undergoes relatively little change

Further, the method and degree to which potentials from the epicardial surface of the heart are transmitted to the extremities have not been settled. According to Wilson and associates,[121] Myers and Klein[59] and others, the potential variations of a given extremity are dominated by those of the precordial surface which faces the extremity. The portion of the heart which faces the extremity depends upon the anatomical position of the heart, the posture of the patient and phase of respiration. As a result, the patterns in aV_L and aV_F are subject to considerable variation in the normal heart. However, the base of the heart which faces the right arm is more or less fixed by attachment to the great vessels, and the pattern in aV_R is more uniform.

There is some discussion as to whether the electrical potentials from that side of the heart facing the left extremity dominate its pattern or whether the pattern is dominated chiefly by the potentials from those *portions of the heart that are in contact with the anterior chest wall.*

Physiologic Considerations: A grasp of the basic elements of the time course of depolarization (activation) of the ventricular musculature is

essential to an understanding of unipolar electrocardiography. As the impulse spreads down the septum through the AV node and bundle of His, the septum is activated before any portion of the free ventricular walls is activated. Thus, the first event revealed in the electrocardiogram is septal depolarization (activation).

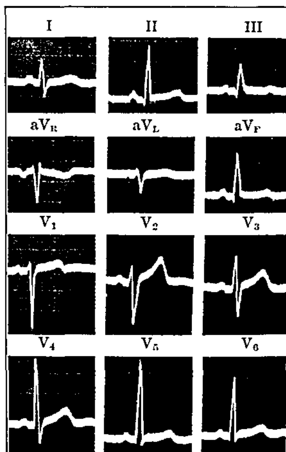


FIGURE 33 Electrocardiographic pattern with heart in vertical position (see page 1299). The ventricular complex in aV_L resembles that of V_1, and aV_F resembles V_6 Note tall R waves in aV_F and deep S waves in aV_L, suggesting a vertical position.

The septum is activated normally from left to right. Thus, there appears to be normally a so-called "physiologic" right bundle-branch block. Since the septum is activated from left to right, an electrode over the right ventricle will reveal an initial small upstroke, the septal r (since the wave of depolarization is passing toward the electrode). An electrode over the left ventricle will reveal a small initial q wave (since the septal activation is in a direction away from an electrode over the left ventricle). Following activation of the interventricular septum, the free wall of the left ventricle is activated from endocardium to epicardium. Thus, a precordial electrode over the left ventricle will reveal a large upstroke (R wave), whereas an electrode over the right ventricular epicardial surface will reveal a large down wave (S wave) (Fig. 24).

During the period of activation of the free left ventricular wall, there will also be activation of the free right ventricular wall. However, the greater muscle mass of the left ventricle will result in the production of stronger electrical forces than those produced by the right ventricular wall. The electrocardiogram then will reveal the predominant left ventricular potential.

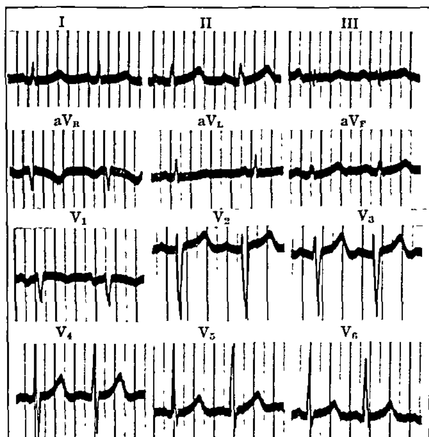


FIGURE 34 Normal heart in semihorizontal position (see page 1299). The QRS complexes in Lead aV$_L$ resemble those of V$_6$, while those of aV$_F$ are small

On occasion, a portion of the right ventricle will be activated after the left ventricle has been completely depolarized. At this point then, right ventricular forces will predominate. An electrode over the right ventricle will reveal a terminal upstroke (r′ wave), whereas a left ventricular electrode will reveal a reciprocal downstroke (s wave).

In summary then, normally an electrode over the right ventricle will reveal an rS wave or an rSr′, whereas an electrode over the left ventricle will reveal a qR or a qRs pattern. The rS pattern is observed characteristically in precordial leads taken from the right side of the precordium and the qR or qRs pattern in leads from the left side of the precordium.

If an rS pattern is seen in aV$_L$, one can assume that right ventricular potential is being revealed in the left arm. If a qR is seen in aV$_F$, the

essential to an understanding of unipolar electrocardiography. As the impulse spreads down the septum through the AV node and bundle of His, the septum is activated before any portion of the free ventricular walls is activated. Thus, the first event revealed in the electrocardiogram is septal depolarization (activation).

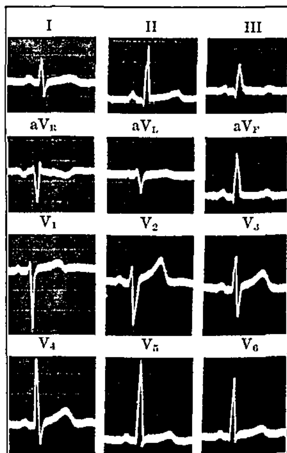


FIGURE 33 Electrocardiographic pattern with heart in vertical position (see page 1299). The ventricular complex in aV_L resembles that of V_1, and aV_F resembles V_6. Note tall R waves in aV_F and deep S waves in aV_L, suggesting a vertical position.

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Illustrating method of application of electrodes for chest leads (see text) To ta'
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To take the V leads, the electrode placement of the exploring electrode is similar to that indicated above The indifferent electrode is connected to the central terminal lead *Insert* Patient turned in left oblique position to illustrate application of axillary leads

Electrocardiographic Positions: Wilson and associates[121] have described six electrocardiographic positions in unipolar limb leads as follows:

Vertical Position: (a) The ventricular complexes of Lead V_L resemble those of Leads V_1 and V_2. *(b)* The ventricular complexes of Lead V_F resemble those of Leads V_5 and V_6.

Semivertical Position: (a) The ventricular complexes of Lead V_F resemble the ventricular complexes of Leads V_5 and V_6. *(b)* The QRS deflections of Lead V_L are small.

Intermediate Position: (a) The ventricular complexes of Leads V_F and V_L are similar in form and size and resemble those of Leads V_5 and V_6.

Semihorizontal Position: (a) The ventricular complexes of Lead V_L resemble those of Leads V_5 and V_6. *(b)* The QRS deflections of Lead V_F are small.

Horizontal Position. (a) The ventricular complexes of Lead V_L resemble those of Leads V_5 and V_6. *(b)* The ventricular complexes of Lead V_F resemble those of Leads V_1 and V_2.

Indeterminate Position: There is no obvious relationship between the ventricular complexes of the limb leads and those of the precordial leads.

Rotation of the Heart: The heart may rotate on its long axis, its transverse axis or its anteroposterior axis Clockwise rotation is said to occur when the right ventricle is rotated toward the left side of the chest and the left ventricle is rotated posteriorly on the long axis of the heart. Counterclockwise rotation occurs when the left ventricle is situated more anteriorly and the right ventricle rotates to the right side of the chest.

The apex of the heart can rotate backward or forward around a transverse axis. When forward rotation of the apex is present, the apex points downward and forward. When backward rotation of the apex is present, the apex points downward and backward.

The heart also rotates on its anteroposterior axis into the horizontal, vertical, and intermediate positions, as previously described.

It should be emphasized at this point that the foregoing discussion concerns the electrical position of the heart; this may or may not be correlated with the anatomical position.

The variations in the patterns of the unipolar limb leads will be discussed below.

The "Augmented Unipolar Leads": The original central terminal of Wilson was constructed on the basis of the Einthoven-triangle theory, one of the corollaries of which states that the body approximates a perfect spherical conductor, with a current source in the center. By mathematical derivation, it is found that if three equidistant points on the circumference of the sphere are tapped electrically, the sum of the potentials at any given instant is equal to zero. Wilson therefore connected electrodes to the three extremities and connected them together at one terminal through three 5000-ohm resistances to minimize the influence of the skin resistance. He called this the central terminal. The several unipolar leads, therefore, consist of an electrode attached to this terminal, theoretically always at zero potential, and the exploring electrode which is attached to the limb, the potential change of which is to be measured (exploring electrode).

Goldberger, by further mathematical derivation, found that if the limb to which the exploring electrode is attached is excluded from the central terminal, the complexes inscribed by the galvanometer will be the same in shape, but fifty per cent taller and therefore more easily discerned. He also suggested that the 5000-ohm resistances be removed, and found that with reasonable care the skin resistances were still negligible. For routine use this has not been accepted, however, and the resistances are generally used with the Goldberger modification. These leads are called "augmented unipolar leads" and are designated as the Wilson leads, but with a small "a" before the other symbols (aV_R, aV_L, aV_F).

Patterns Observed in Unipolar Limb Leads

Discussion of the patterns in the unipolar limb leads is based chiefly on the work of Wilson and associates,[121] Goldberger,[130] and Myers and associates.[59]

Lead aV_R: The major deflection of ventricular origin in aV_R is derived from the potential variations of the endocardial surfaces and cavities of the two ventricles and consists of a downward QRS and inverted T wave. The basic normal QRS pattern is subject to the following variations: (1) a QS complex; (2) a minute r followed by a deep S (rS); a deep Q followed by a late R (QR); and a small r and r′ separated by a deep S (rSr′). The P wave is always inverted. The electrophysical reasons for these patterns are discussed under "Intracardiac Electrocardiography."

Deviations from the Normal Pattern in aV_R: A late R of increased amplitude may be observed in right ventricular hypertrophy due to potentials from the epicardial portion of the hypertrophied right ventricle; in right bundle-branch block it is accompanied by widening and notching of the QRS complex; in left ventricular hypertrophy, owing to activation of the posterobasal portion of the left ventricular wall, a late R wave is present. The presence of an upright T wave is abnormal, and is due to factors that produce an abnormal upright T wave in the endocardial potentials of the left ventricle (*e. g.*, left ventricular hypertrophy). Elevation of the RS-T segment may be observed in association with an injury current involving the subendocardial portion of the ventricle, *e. g.*, digitalis and subendocardial infarction. RS-T segment depression is observed in acute pericarditis, particularly involving the epicardium of the left ventricle and in the presence of other types of epicardial injury.

Lead aV_L: The basic patterns in aV_L are subject to considerable variation because this portion of the heart is free to rotate about an anteroposterior, transverse and logitudinal axis. The P wave in aV_L may be upright, flattened, diphasic or inverted, depending upon the position of the heart.

Basic Patterns in aV_L: The following are the basic patterns observed normally in aV_L:

Left Ventricular Pattern as Observed in V_5 or V_6: This pattern is observed when the anterolateral aspect of the left ventricle faces toward the left arm and when the heart is tilted on its anteroposterior axis into

an oblique or horizontal position. The T wave is usually upright and is occasionally flattened.

Right Ventricular Pattern as Observed in V_1 or V_2: This pattern is observed when the heart drops into a vertical position on its anteroposterior axis and undergoes concomitant clockwise rotation on its longitudinal axis. The anterior wall of the right ventricle may be brought into a position where it faces the left arm, thus leading to the transmissions of these potential variations to the left arm, resulting in ventricular complexes of the rS type. The T waves usually are upright, but may be diphasic or inverted.

QRST Pattern of the Type Observed in Transitional Zone (Generally V_3): When the heart is placed in a semivertical position and rotated moderately in a clockwise direction on its longitudinal axis, the anterior margin of the interventricular septum may face toward the left arm. In this state the QRS complex resembles that observed in the transitional zone; it is low in voltage, consists of two or more phases of apparent equal amplitude, and is often notched. The T wave is upright or flattened.

Resemblance to Pattern Obtained in Esophageal Lead at Auricular Level: When the heart is situated in a vertical position and displays counterclockwise rotation on a longitudinal axis, the potential variations may be obtained from the left atrium and the mitral orifice. This results in a deep Q wave and a small r derived from the posterobasal aspect of the left ventricle. The Q is large and the r wave may be small or absent (Qr pattern). The inverted P wave resembles that observed in the esophageal lead from above the heart. The T wave is characteristically inverted. A QS pattern is observed when counterclockwise rotation is present and the mitral orifice faces the left shoulder.

Deviations from the Normal Pattern in aV_l: A Q wave of significant duration and depth is seen in mural infarcts involving the anterolateral wall of the left ventricle, in anteroseptal infarcts when there is clockwise rotation and in posterolateral infarcts when there is counterclockwise rotation. When the infarct is extensive and transmural, the R wave will disappear and a QS deflection which is slurred will be present. Abnormality of the QS in aV_L is significant if (1) it is preceded by an upright P wave; (2) if the QS is slurred and widened, especially if the slurring is on the downward limb of the QS; (3) when there are significant RS-T segment signs of infarction.

RS-T segment elevation is seen in acute pericarditis and in infarction involving the lateral wall of the left ventricle or the left half of the interventricular septum; and a persistent RS-T segment elevation is seen in ventricular aneurysm involving the anterolateral wall of the left ventricle. RS-T segment depression is seen as a result of digitalis effects, in subendocardial infarction of the left ventricular cavity, in infarction of the posterior wall of the left ventricle, and in infarction of the right half of the interventricular septum.

The configuration of the T wave depends on the portion of the heart facing the left shoulder and on the type and degree of pathologic changes in the heart.

Lead aV_F: The QRST patterns in aV_F are subject to considerable variations in normal persons. A given rotation tends to produce reciprocal effects in aV_F to those in aV_L.

Basic Patterns in aV_F: There may be said to be present four basic patterns in aV_F.

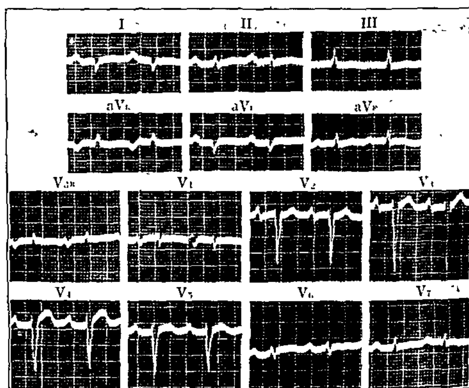


FIGURE 36 Heart in vertical position with marked clockwise rotation Note normal QS in aV_L. A marked right axis deviation is present in the standard limb leads In Lead aV_R the main QRS deflection consists of an R wave which is slurred on the downstroke Lead aV_L consists of a QS deflection with the upstroke being slurred Lead V_6 represents the transitional zone. Lead V_{3R} shows a QRS deflection similar to aV_R. This case represents clockwise rotation in the anteroposterior axis with marked clockwise rotation in the longitudinal axis and rotation of the transitional zone into the left axilla Thus, Leads aV_R and V_{3R} are tapping the posterobasal wall of the left ventricle, and Lead aV_L is tapping potentials of the right atrioventricular junction The right half of the interventricular *septum faces anteriorly, as can be seen by examination of Leads V_2 to V_5* Most of the left ventricular potentials are transmitted to the diaphragm since Leads aV_F and V_7 resemble each other

Right Ventricular Pattern (rS) Resembling That Normally Seen in V_1 or V_2: Rarely a QS complex may be obtained in aV_F similar to that observed in V_1. In patients with normal hearts who present a QS deflection, an R wave tends to appear with respiration and is usually demonstrable when the electrocardiogram is taken in another position. The T wave may be upright, flattened, diphasic or inverted.

Transitional Zone RS: This pattern is observed when the potential variations below the diaphragm are dominated by the interventricular

septum. The upward and downward deflections of QRS are approximately equal in amplitude and may appear slurred or notched.

Left Ventricular Pattern qR (V_5 and V_6): This pattern is observed with the heart in an oblique or vertical position, with clockwise rotation on the longitudinal axis so that the potential variations of the posterior apical wall of the left ventricle are transmitted to the diaphragm and then to the left leg. In this pattern the main deflection of QRS is an R wave The R wave is often preceded by a small Q not exceeding 0 02 second and twenty-five per cent of the amplitude of the succeeding upright deflection. The T wave is upright but may be flattened.

Resemblance to Pattern Obtained in Esophageal Leads Opposite the Posterobasal Aspect of the Left Ventricle: This pattern may be observed with the heart in a vertical position with the apex displaced forward, bringing the posterobasal aspect in closer contact with the diaphragm. This pattern resembles that obtained in esophageal leads near the AV groove. A distinct Q wave is present. It is fairly large in amplitude and there is a relatively tall R which is usually more than four times the amplitude of Q. The T wave is usually inverted but may be diphasic, flattened or upright.

Deviations from the Normal Pattern in aV_F: A Q wave which is more than 0.04 second wide and thirty per cent or more of the succeeding R wave is seen in myocardial infarction involving the posterior wall of the left ventricle. This Q wave or QS deflection is to be distinguished from that found where the left-leg potential taps the posterobasal aspect of the left ventricle. This may occur rarely when the heart is in the vertical position with the apex rotated forward on the transverse axis.

The RS-T segment is elevated in myocardial infarction involving the posterior wall of the left ventricle, in subendocardial infarction involving the anterior wall of the left ventricle, and infrequently in pericarditis involving the posterior wall of the left ventricle. The RS-T segment is depressed in subendocardial infarction of the posterior wall of the left ventricle, in a transmural infarct of the anterior wall of the left ventricle and in digitalis effects.

The T wave may show a left ventricular hypertrophy pattern when the heart is in a vertical position with clockwise rotation on the anteroposterior and longitudinal axis

Electrocardiogram in the Various Electrical Positions of the Heart

Wilson and his associates[158] defined six different electrocardiographic positions of the heart as follows: vertical position, semivertical position, intermediate position, semihorizontal position, horizontal position, and indeterminate position. However, they were careful to note that the electrocardiographic position was not determined by the anatomic position, "either when this organ is normal or abnormal." According to this definition, in an electrically vertical position "the ventricular complexes of Lead V_L resemble those of Leads V_1 and V_2 and the ventricular complexes of Lead V_F resemble those of V_5 and V_6." When such an electrocardiographic position is present, the forces of activation are directed downward, to the right and somewhat anteriorly. The limb leads record the

inferior orientation of the QRS forces as relatively tall R waves in Leads II, III *and* aV_F; *the rightward orientation of the QRS forces is recorded* as an S wave in Lead I, giving rise to the so-called right axis deviation. The precordial Leads V_{3R}, V_1 and V_2 tend to record relatively tall R waves because their axes are parallel to those forces which are directed to the right and anteriorly.

The concept of electrical position has been further amplified by Goldberger,[165] Myers and his associates,[166] and others. However, more recently the usefulness of this concept has been questioned. Certainly any correlation between anatomic and electrocardiographic position is nonexistent. Furthermore, anatomic rotation about the long axis of the heart remains unproved. Even with right and left ventricular hypertrophy, when rotation is thought to be most likely, the changes generally considered *to be due to anatomic rotation can be explained in* another manner. It has been shown by Prinzmetal and his colleagues[157] that the direction of the forces of recorded depolarization depend chiefly upon the action current of the epicardial surface of the heart and a thin portion of the septum. When the left ventricle is enlarged (a greater epicardial surface is present), a longer-continued as well as dislocated action potential is present. The terminal forces, by this time, unopposed by right ventricular forces, are oriented posteriorly and superiorly, accounting for the large lateral and superior potential seen in this abnormality. When the right ventricle is enlarged, the epicardial surface of the right ventricle is now larger than normal and the electrical forces extend anteriorly, inferiorly, and at times superiorly, thereby accounting for the so-called electrical vertical position of the heart. These alterations take place in the absence of any anatomic rotation.[167]

The Value of Unipolar Limb Leads

The following advantages have been attributed to unipolar limb leads:

1. The spread of the stimulus through the heart can frequently be followed easily by these leads.

2. They demonstrate the electrical position of the heart in the chest, and the type and degree of rotation.

3. From a clinical standpoint, they are of value in (*a*) the interpretation of axis deviation; (*b*) the determination of the significance of the Q wave, particularly Q_2 and Q_3; (*c*) the diagnosis of small myocardial infarcts, particularly those on the posterior lateral wall; (*d*) evidence of ventricular hypertrophy; (*e*) in certain instances, alterations are observed in the unipolar limb leads when the standard leads are relatively normal and minimal changes are observed in the precordial leads.

In considering the advantage of the unipolar limb leads one must also consider the following difficulties in their interpretation:

1. As has been discussed above, there are wide variations in the QRST patterns within the normal range. There are four main normal patterns with minor subpatterns in aV_R, four in aV_L, and four in aV_F. Unfortunately, the electrocardiographic patterns that are a normal variant may be abnormal with the heart in certain electrical positions.

2. These patterns are markedly affected by posture and the phases of respiration.

3. It is frequently difficult to establish the transitional zone and to explain some of the patterns on the basis of rotation.

4. The positions of the cardiac chambers and the septum are difficult to establish in life even with the newer types of roentgen technics, including angiocardiography.

5. The replacement of the unipolar limb leads of Wilson by Goldberger's aV leads has been questioned by some investigators on an electrophysical basis.[131]

THE PRECORDIAL LEADS

In addition to the three indirect or limb leads and the "unipolar limb leads," precordial leads are usually employed Their value in the diagnosis of coronary occlusion was first established by the work of Wolferth and Wood[2] and later by Wilson and associates.[4 7] Since that time, they have proved of value in the recognition of many other conditions, *e. g.*, acute pericarditis, digitalis effects, site of origin of bundle-branch block, right and left ventricular hypertrophy, and myocardial damage of various types.

An electrode 3 cm. in diameter is applied to various regions of the precordium, as noted below. This is coupled with an electrode placed on the left leg, angle of the left scapula, right arm, left arm, or with a central terminal which is connected with the three extremities through a resistance of 5000 ohms. The electrode placed in the precordial region is the most important, for upon its position chiefly depends the configuration of the resulting (precordial) electrocardiogram.[8 10] Alteration of even a few inches in the position of this electrode may definitely change the character of the electrocardiogram. The electrode close to the heart is called the *exploring* electrode. The electrode placed on the arm, leg or at the central terminal is called the indifferent electrode because change of its position alters the electrocardiogram little or not at all. *Since the situation of the exploring electrode is extremely important for correct electrocardiographic interpretation, its placement should not be left to a technician unless he or she has been thoroughly trained in this work.*

Standardization of the Precordial Leads

Early in the use of precordial leads, considerable confusion resulted from the fact that various investigators used different positions for the precordial leads and different methods of applying electrodes. This confusion has been largely obviated by the Committee of the American Heart Association and the Cardiac Society of Great Britain and Ireland, which have recently recommended a standard method for applying the electrodes and a nomenclature to be used in describing precordial leads[11]:

Some of the important recommendations follow:

Nomenclature: When *a lead from a single point in the precordium* is used, the exploring electrode should be placed at the apex and the

following terminology applied, depending upon the location of indifferent electrodes:

IV_R—Apex to right arm.
IV_L—Apex to left arm.
IV_F—Apex to left leg.
IV_T—*Apex to central terminal.*

When leads from two or more precordial points are employed, it is suggested that the precordial electrode be paired with an electrode on the left leg or right arm. It is suggested further that the letters CF or CR be used, followed by a subscript, to designate such leads, *e. g.*:

CR_1—Right margin of sternum to right arm.
CR_2—Left margin of sternum to right arm
CR_3—A point midway between the left margin of the sternum and the left midclavicular line to right arm.
CR_4—Left midclavicular line to right arm
CR_5—Left anterior axillary line to right arm
CR_6—Left midaxillary line to right arm.
CR_7—Posterior axillary line to right arm.
CR_8—Midscapular line to right arm.

If the left leg, instead of the right arm, is used for the indifferent electrode, F is substituted for R in the above; if the central terminal is the site of the indifferent electrode, the letter V followed by a subscript is used to designate such leads. Thus, we should have CF_1, CF_2, V_1, V_2, etc.

"The position of the precordial electrode shall be indicated by the subscript used according to the following plan: subscript $_1$ shall be used for the right margin of the sternum; $_2$, for the left margin of the sternum; $_3$, for a line midway between the left margin of the sternum and the left midclavicular line; $_4$, for the left midclavicular line; $_5$, for the left anterior axillary line; and $_6$, for the left midaxillary line. When the letters and subscripts specified are employed it shall be understood that in the case of the sternal leads the precordial electrode has been placed in the fourth intercostal space, and that in the case of the other leads it has been *placed upon a line drawn from the left sternal margin in the fourth* intercostal space to the outer border of the apex beat (or to a point at the junction of the midclavicular line and the fifth intercostal space) and continued around the left side of the chest at the level of the apex beat of the junction mentioned."[12]

The galvanometric connections are made in such a way that relative positivity of the precordial electrode is represented in the finished curve by an upward deflection and relative negativity of this electrode by a downward deflection.

This method makes it possible to assign the letters QRS to the individual deflections of the primary ventricular complex in exactly the same manner as the standard limb leads.

As a routine, six precordial leads should be taken in the C_1, C_2, C_3, C_4, C_5, and C_6 positions.

In a supplementary report, a committee of the American Heart Association (1943)[111] made certain new suggestions and recommendations relative to the use of precordial leads. It is agreed that a single precordial lead from the region of the apex or the region of any other part of the precordium is inadequate. The Committee further believes that three is the least number of leads that can be regarded as satisfactory. For this purpose, Leads C_1, C_3, and C_5 are to be used, though it is urged that C_1, C_2, C_4, and C_5 be used whenever possible. In the anteroseptal type of infarction the only evidence of RS-T deviation is in the C_2 and C_3 positions. Unless tracings are taken in these locations, the diagnosis would be missed. If the heart is enlarged to the anterior axillary line, an additional lead, C_6, should be used. It must be remembered that inversion of the T wave in the C_1 position is frequently encountered in normal subjects.

For the purpose of thoroughness it is advisable routinely to take six precordial leads, C_1, C_2, C_3, C_4, C_5, and C_6. The electrocardiographic pattern thus obtained will be of help in the diagnosis of various types of myocardial infarction, ventricular hypertrophy as well as myocardial abnormality localized to a small portion of the precordium. The C_1 position not only is of value in delineating the electrocardiographic pattern in right ventricular hypertrophy but also is often of help in giving a more accurate picture of the electrical potential of the right arm. This is of value in the study of right auricular hypertrophy and auricular arrhythmias Occasionally a lead taken farthur to the right (C_3R or V_3R) is of additional help. This precordial electrode is placed on the right side of the chest in a position similar to that of CR_3 or V_3 on the left side of the precordium. This lead is of additional help in the diagnosis of right ventricular hypertrophy.[13,121]

The Precordial Zones: The electrocardiographic patterns in precordial leads may be divided into three zones: (1) those over the right side of the precordium, (2) the transitional zone, and (3) those over the left side of the precordium. This approach is of help in correlating the electrocardiographic patterns with the portions of the heart beneath the electrode whose potential is recorded, and in helping to define more clearly varying degrees of rotation, clockwise and counterclockwise

Precordial Leads over the Right Side of the Precordium (V_1 and V_2, Occasionally V_3): These are associated with small and occasionally absent R waves in V_1 and deep S waves.

The Transitional Zone: The transitional zone is situated over the interventricular septum and is characterized by an almost equal amplitude of R and S. The transitional zone is usually situated in chest positions 3 and 4. It may be shifted to the left in clockwise rotation, as is observed particularly in right ventricular hypertrophy and also in left ventricular hypertrophy where the transitional zone may be observed at position 4, 5, or 6.

Leads over Left Side of Precordium: The leads over the left side of the precordium tap the left ventricular potential and are characterized by a small Q wave and by a tall R wave with or without a small S wave. In marked degrees of clockwise rotation this may be shifted over to posi-

ECG IN NORMAL CHILDREN—(ZIEGLER)

The following table gives the amplitude of the R and S waves in the right (V_1 and V_2) and left (V_4 and V_6) precordial leads at various ages.

R AMPLITUDE, MV/10

	V-1			V-2			V-4			V-6		
	Ave.	Min	Max.	Ave	Min.	Max.	Ave.	Min.	Max.	Ave	Min	Max.
0—24 hours	17	3	23	21	3	41	19	3	32	5	0	11
1—7 days	17	4	29	21	5	43	20	3	35	6	1	16
1—4 weeks	14	5	25	20	8	33	19	6	37	8	1	24
1—6 months	11	4	20	19	8	30	22	11	37	10	4	22
6—12 months	11	3	17	19	8	28	25	11	33	13	4	20
1—5 years	9	3	19	15	3	26	23	10	41	12	5	25
5—12 years	7	3	20	11	3	28	26	7	60	14	8	24
12—16 years	6	1	16	9	2	20	24	7	51	14	5	20

S AMPLITUDE, MV/10

	Ave	Min	Max	Ave.	Min.	Max.	Ave.	Min	Max	Ave.	Min.	Max.
0—24 hours	10	0	28	22	1	42	23	0	42	5	0	13
1—7 days	11	0	25	22	1	36	13	0	30	3	0	13
1—4 weeks	7	0	18	17	3	28	10	0	18	3	0	10
1—6 months	7	1	21	15	3	35	11	0	30	2	0	6
6—12 months	8	1	18	18	6	37	11	0	28	2	0	4
1—5 years	12	0	37	22	10	44	7	0	19	1	0	4
5—12 years	14	5	26	23	11	41	8	1	20	1	0	5
12—16 years	15	5	46	24	8	52	6	1	17	1	0	5

R AMPLITUDE OR % RS

	V-1	V-2	V-4	V-6
0—24 hours	62	49	44	48
1—7 days	58	49	56	65
1—4 weeks	66	52	63	77
1—6 months	62	55	68	82
6—12 months	56	50	70	87
1—5 years	43	40	78	94
5—12 years	38	36	77	93
12—16 months	27	28	79	91

tions 5 and 6 or 6 and 7. In counterclockwise rotation this may be shifted to position 4 or 4 and 5.

In anterior myocardial infarction, anteroseptal infarction and certain types of bundle-branch block the transitional zone is not clearly defined.

The Indifferent Electrode: There is no definite recommendation as to the best position for the remote electrode with which the exploring or

precordial electrode is paired. The precordial electrode may be paired with the electrode (1) on the right arm, (2) on the left leg, or (3) with a central terminal which is connected and each of the three extremities through a resistance of 5000 ohms. It has been observed that when the precordial electrode yields a normal curve when one indifferent electrode is used, it may occasionally yield an abnormal curve when another is used. The most informative location of the indifferent electrode for a specific heart lesion has not yet been settled. In posterior myocardial infarction the left leg lead (CF lead) often shows changes not seen in the right arm (CR lead). In general, the tendency recently has been to use the Wilson central terminal (V leads). However, from a clinical standpoint, there is little difference between the electrocardiographic pattern of CR and V leads.

Physiologic Considerations Concerning the Use of Precordial Leads

The use of precordial leads has been a most important advance in electrocardiography in the past decade. It occurred at a time when many cardiologists considered that the limits of our knowledge concerning the electrocardiogram had been almost reached. What information do the precordial leads give us which cannot be obtained by limb leads?

The electrocardiograms obtained by precordial leads resemble very closely the records obtained by placing an electrode directly over the heart muscle (electrogram). They have the advantage of recording at close proximity the electrical events of the heart. By their use, we are, in effect, putting a higher magnification of the microscope over a given cardiac area. Moreover, each precordial electrode records electrical events occurring beneath the electrode, so that we can follow the condition that exists in various areas of the heart muscle without neutralization or summation of other areas as occurs in limb leads. For example, Wolferth and his coworkers have shown that Lead I represents the electrical potential of C_5 after it has undergone decrement minus the electrical potential of C_1 after it has undergone decrement.[120] Further discussion of the method by which the precordial leads record the electrical potential from various portions of the precordium and by unipolar limb leads will be given below.

The Term "Unipolar Leads": If one electrode is placed in a solution near a muscle strip and the other electrode is placed in the solution at a considerable distance from the muscle strip, the resulting electrical potential is due to the potential of the muscle strip. The farther away the indifferent electrode is placed from the muscle the less of the muscle potential it records and the closer its potential is to zero. This electrode used to record the muscle potentials may be called a "unipolar lead" because the potential variations are recorded predominantly by the electrode close to the muscle strip.

The precordial leads and the unipolar extremity leads are sometimes called "unipolar leads." This term as applied to the human subject has definite limitations. They are not true unipolar leads in the sense that they are applied to the muscle strip discussed above, because the precordial leads are situated at a distance from the heart separated by variable conductive media. This is even more true of the "unipolar limb" leads. The

indifferent electrode is not zero and in the case of the left leg and other extremity leads may have an appreciable potential of its own. In the human, intracavity leads may be considered to be unipolar. Esophageal leads probably also belong to this category. In these conditions the electrode is either in or so close to the heart and the magnitude of its potential is so great as compared to the indifferent electrode that the electrocardiogram is little affected by the distant electrode.

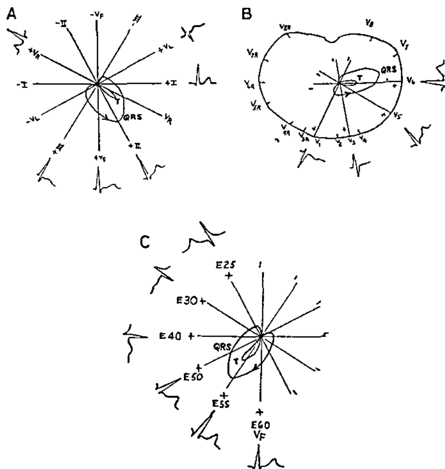


FIGURE 37.

Effects of Position of the Heart on the Electrocardiogram of Precordial Leads: That the alteration of the heart's position has an effect on the limb leads has long been recognized, but the manner in which it affects the precordial leads is not generally appreciated. It should be remembered that the correlation between the anatomic and electrocardiographic positions, while not perfect, is quite close.

There is considerable evidence[109,110,120] that potential variations of the right arm are similar to the potential variations of those parts of the heart that are nearest to the right shoulder, that the potential variations of the left arm resemble the potential variations of those parts of the heart that are nearest the left shoulder and that the potential variations of the left leg are

like the potential variations of the heart's diaphragmatic surface (Fig. 31). When the electrocardiograms are taken from both shoulder regions with electrodes paired across the root of the arm, the ventricular deflections are, as a rule, very small, whereas those from the left arm are of much greater amplitude.[120] When the heart assumes a vertical position or turns about on its own axis, so that the left ventricle is below the right, the potential variations of the left ventricular surfaces are transmitted to the left leg and those of the right ventricular surfaces are transmitted to the left arm. When the heart assumes a more horizontal position or twists about its own axis in the direction required to bring the right ventricle below the left, the effects upon the potential variation of the left arm and left leg are the reverse of those described. In the intermediate position, the potential variations of the right and left ventricles are about equally transmitted to the left arm and left leg.[121]

In the precordial leads, the configuration of the QRS complexes will vary if the left arm and the left leg electrodes are used as the indifferent electrode.[121] However, the configuration of the QRS complexes is relatively constant when the right arm or the central terminal is used as the indifferent electrode. Therefore, as Wilson[121] has stated, when the heart is normal, the precordial electrocardiogram has the same form regardless of whether the limb leads show right axis deviation, no deviation, or left axis deviation. The above demonstrates another advantage of precordial electrocardiography; namely, it will tend to give fewer false readings in the normal heart and tend to give more abnormal readings in the presence of ventricular hypertrophy and bundle-branch block.

Significance of the Electrocardiographic Deflections (Bipolar and Unipolar Leads)

In the electrocardiogram, a deflection from the baseline (0 potential difference) is evidence that a potential difference exists between the two electrodes connected to the galvanometer (Fig 170 *A*). This potential difference is dependent upon the electromotive forces originating in the heart and their distribution to the body surface. Since the object of electrocardiography is to study the original forces as they are produced by the heart, and since these forces may be oriented in all three dimensions, a sufficient number of leads must be obtained so that all three dimensions will be represented. In order to make tracings of potential differences in one person which may be compared to those of other persons, the electrode position or placement has been standardized.[160]

The potential difference (deflection) recorded by a particular pair of electrodes depends on the following three factors: (1) the distance of the electrodes from the point of origin of the force (heart); (2) the conductivity of the tissues between the heart and the electrodes; and (3) the quantity of the original force directed at either of the two electrodes. With few exceptions, factors 1 and 2 may be ignored in the bipolar extremity leads. If this assumption is made, the recorded deflection depends on the *position of the electrodes on the body (effective electrode axis—an imaginary* line extending from one to the other electrode) and the quantity of

the force parallel to this axis. That means that all forces parallel to this axis will be recorded in full, and those forces at an angle to this axis will be recorded in part. (The part recorded will be the original force times the cosine of the angle between the direction of the force and the axis.)

In the precordial leads (CR, CF or CL) the distance between the heart and the chest electrodes cannot be ignored, since electrodes close to the heart[158] exaggerate potentials which originate close to the electrode (the electromotive force recorded at any point is inversely proportional to the square of the distance between the point of recording and the point of origin of the force). Although this is a disadvantage of chest electrodes as far as mathematical expression of the forces is concerned, it is often considered to be an advantage clinically, since many investigators believe *that localized abnormal potentials may be recorded only in this manner.* The foregoing remarks are also applicable to esophageal and intracardiac leads.

In 1934 Wilson and his associates[161] introduced the "central terminal" in an effort to obtain an indifferent electrode, the potential of which was close to zero. The maximal variation in potential of this terminal has been said to be not more than 0.003 millivolt. (This has recently been questioned by Frank and Kay.[162]) Any electrode paired with the central terminal was considered to represent a unipolar lead. The unipolar extremity leads (Fig. 170 *A*) V_R, V_L, and V_F are obtained by placing the exploring electrode on various positions on the chest[160] and coupling this electrode with the central terminal of Wilson. Unipolar leads were originally thought *to represent the absolute variation in potential beneath* the exploring electrode, as contrasted to bipolar leads (I, II, and III), which were thought to record a mixture of electrical forces because they represented a difference in potential between two points. Wilson *et al*,[158] considered unipolar precordial leads to be "semi-direct" leads, influenced principally by the myocardium underlying the exploring electrode. However, they were aware that even in direct epicardial unipolar leads the truly local effects are represented only by the "intrinsic deflection" and stated that "although the excitation of the muscle in contact with the exploring electrode produces a much larger and much more sudden fluctuation in the potential of this electrode than the excitation of any equal mass of muscle at a great distance from it, every unit of ventricular muscle, without exception, produces action currents which contribute to the form of these complexes."

The work of Einthoven and his colleagues[163] in the calculation of the mean electrical axis from the standard limb leads included only the frontal plane. Duchosal and Sulzer[164] concluded that Einthoven's hypothesis was valid for any plane, and for any lead on the body surface. They felt that the spread of electrical activity through the heart could be represented at any instant as a single equivalent point of origin of EMF, the voltage recorded by a precordial or other lead being determined by the relation of the axis of the point source to the axis of the lead, and influenced by the [illegible] n electrocardio- [illegible] heart, the prin- [illegible] vide additional

axes and that if an electromotive force is more nearly parallel to a particular axis, a more positive or negative deflection will be recorded.

*The Normal Precordial Leads**

The precordial leads differ normally within rather wide limits. The variation depends upon the configuration of the heart, its position and the placement of the precordial electrode. In comparing different tracings on the same patient, it is important that this electrode be placed in the same position.

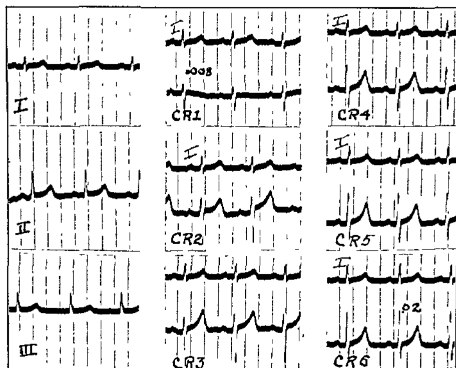


FIGURE 38 Normal tracing with simultaneous registration of precordial leads CR_1 to CR_5, with Lead I Note that the intrinsic deflection in CR_6 is only slightly behind that of CR_1

The pattern of the QRS complexes in the normal precordial leads depends chiefly upon (1) the position of the exploring electrode and (2) to a lesser degree, the site of the indifferent electrode.

Since the electrodes are placed on arbitrary points on the chest and because the portion of the heart immediately beneath the electrode determines the potential differences of the exploring electrode, the configuration of the ventricular complexes may be expected to vary in different sizes and shapes of hearts and in different chest types. For example, in a ptotic heart, the left ventricle may be situated between the C_2 and C_4 positions, whereas in a transversely placed heart the left ventricle may be in the C_4 position or still farther to the left (C_5).

* Refer to pages 1305-1306 for chest lead nomenclature

That the position of the indifferent electrode may modify the electrocardiogram in the precordial leads has also been demonstrated. In the past five years we have used the right arm as the site of the indifferent electrode. We shall discuss the pattern of the V leads in a patient of normal build. The leads used are V_1, V_2, V_3, V_4, and V_5 (Fig. 38). In V_1, the amplitude of the QRS is small (4 to 6 mm.), the R wave is small (1 to 2 mm.) and the T wave is flattened and occasionally inverted. In V_2, the QRS complex is of normal amplitude, averaging 8 to 12 mm. The amplitude of R is about one-third the amplitude of S. In the V_3 position, the amplitude of R increases slightly above that of V_2. In V_4, the R and S are of about equal amplitude. In V_5 and V_6, the amplitude of the R wave is greater than that of the S wave. The width of the QRS complex in the precordial lead may be slightly above that in the limb leads. The T waves are normally upright from V_3 to V_5 positions. Diminished amplitude of the T wave may occur in transversely placed hearts. Slight deviation of the RS-T segments up to 2 mm. may occasionally be observed in normal hearts. These deviations may persist unchanged for long periods of time.

The supplementary report of the Committee of the American Heart Association on the Standardization of Precordial Leads[111] has indicated that certain relations exist between the size of the deflections in the three limb leads and those found in the corresponding deflections in the precordial leads. The following numerical relations are pointed out, referring to, in each case, the values in millimeters of any synchronous points in the leads mentioned, such as is usually found in the peak of T:

$$\text{Lead } IV_F = \text{Lead } IV_R + \text{Lead II}$$
$$\text{Lead } IV_L = \text{Lead } IV_F + \text{Lead III}$$
$$\text{Lead } IV_T = \text{Lead } IV_F + \tfrac{1}{3}\,(\text{Lead II and Lead III})$$

By means of these formulas it is possible to determine the deflection in Lead IV_F if we have obtained Lead II and Lead IV_R. Leads IV_L and IV_T can be similarly obtained, provided that synchronous points in the curve are considered.

Information to Be Gained from Precordial Leads: The question frequently arises as to whether or not precordial leads should be used routinely in all cases. The answer is that they should be used in practically all instances, since they may add to the information furnished by the indirect leads in the following conditions: (1) in the anginal syndrome, in acute myocardial infarction, and in the presence of coronary artery disease; (2) in myocardial damage of any type; (3) in acute pericarditis; (4) in right or left ventricular hypertrophy; (5) in bundle-branch block; (6) in any condition associated with anoxia; (7) in noting the effects of drugs, particularly digitalis. The precordial leads, being relatively uninfluenced by factors distant from the area explored, record more accurately the electrical activity of the muscle immediately beneath the electrode.

Abnormalities in the Precordial Leads

R Wave: The R wave often disappears or is markedly reduced in amplitude in the acute, subacute and chronic stages of anterior apical infarc-

[illegible]

tion. Its disappearance in the acute stage may be permanent. It may return partially or entirely in the subchronic and chronic stages of infarction. These alterations in the R wave may be limited to the CR_2 or CR_3 position in anteroseptal infarction or may involve the CR_4 and CR_5 positions with extensive apical infarction. After healing takes place, the R wave may return in those precordial positions under which the muscle has returned to a more or less normal state.

In left bundle-branch block, the R wave is small (1 to 2 mm.), from the C_1 to C_4 positions, since the transitional zone is moved farther to the left. In the presence of cardiac enlargement due to left ventricular hypertrophy, dilatation, or both, the R wave may be small (1 to 5 mm.) from C_2 to C_5 positions for the same reason. In right ventricular hypertrophy, the R wave is larger than or equal in amplitude to the S wave from CR_2 to CR_5 positions.

QRS Complex: Low amplitude of the QRS complexes (below 5 to 6 mm.) in all precordial leads (CR) is usually associated with low amplitude of the QRS complexes in the limb leads and signifies a severe grade of myocardial damage, usually secondary to coronary artery disease,[125] but may be the result of extracardiac factors, especially anasarca and large pleural effusion.

Slurring of the QRS complex of the M type, if present in one or several precordial leads, is usually associated with muscle damage.

RS-T Segment: Elevation of the RS-T segment signifies a current of injury immediately beneath the exploring electrode.* Only the anterior and the lateral walls of the left ventricle can be directly tapped by exploring electrodes. In these two instances a precordial electrode placed directly over the injured area would yield an elevation of the RS-T segment. Other parts of the left ventricle are distant from the exploring electrode, and, in the case of the posterior wall, the injured muscle is situated opposite to the exploring electrode, which is usually placed on the anterior chest wall. In view of the relation of the injured area to the exploring electrode (namely, situated on the opposite side of the heart from the portion tapped), the RS-T segment is depressed.

Elevation of the RS-T segment in precordial leads CR_2 to CR_6, when associated with the absence of the R wave, is observed characteristically in anterior transmural infarction. This may be observed only in CR_2 or CR_3 in anteroseptal infarction, in CR_4 and CR_5 in apical infarction, and in CR_5 and CR_6 in anterolateral infarction. When the infarct is superficial, involves only the subepicardial portion of the myocardium and does not extend through the entire depth of the myocardium to the endocardium, elevation of the RS-T segment is present without alteration in the amplitude of the R wave. In lateral infarction, the R wave is preserved in the CR_2 to CR_5 positions and may be absent in CR_6 and sometimes in the CR_5 position.

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* An exception to this was reported by Hellerstein and Katz[132] in the dog. They observed RS-T segment elevation in the anterior electrode following acute injury to the subendocardial portion of the posterior wall of the left ventricle.

Elevation of the RS-T segments in all precordial and limb leads occurs in acute pericarditis and in the anteroposterior type of myocardial infarction. We have also seen this pattern in acute diffuse myocarditis without pericardial involvement.

Depression of the RS-T segment when the electrode is placed on the anterior chest wall suggests the possibility of an infarct distant from the exploring electrode or of injury on the endocardial portion of the myocardium directly beneath the electrode.

Depression of the RS-T segment in Leads CR_4 and CR_5 is seen in posterior infarction, and in CR_5 and CR_6 with posterolateral infarction.

Depression of the RS-T segment may also be observed in various conditions involving anoxia, *e. g.*, pulmonary embolism, anginal seizures, shock-like states, toxic conditions, in association with tachycardia, and resulting from the action of certain drugs, especially digitalis.

T Wave: Tall T waves almost equal in amplitude or exceeding that of the R wave are observed in the subacute stage of myocardial infarction. These are upright in the posterior and inverted in the anterior infarction (Fig. 56). Diminution in amplitude or flattening of the T waves is due to myocardial abnormality, either structural or resulting from severe disturbances in function. Inversion of T waves (except occasionally in children) in CR_3, CR_4, CR_5, and CR_6 is due to myocardial abnormality. Occasionally, it is the only electrocardiographic abnormality present. The T wave inversion may be of the nondescript myocardial type or may be cove-shaped in the presence of coronary artery disease. Inversion of the T wave in CR_1 and occasionally in CR_2 may be a normal finding.

In mild grades of coronary insufficiency and in the subacute stage of pericarditis the terminal portion of the T wave shows a downward dip.

The Juvenile Pattern: The so-called "juvenile pattern" in the electrocardiogram is observed in infants, children, and occasionally in young adults. It is characterized by the presence of inverted T waves in $CR_{1,2,3}$ and occasionally in the CR_4 position The T-wave inversions tend to become less marked as the CR_3 and CR_4 positions are attained. When T-wave inversion persists up to the CR_5 position, and if there is no difference in the degree of T-wave inversion from the standpoint of becoming less marked in the CR_4 position, the alterations are probably the result of myocardial abnormality or digitalis effects.

The inverted T wave observed in these positions is presumably due to the relatively greater right ventricular weight in children than in adults and because more of the right ventricular surface faces the anterior chest

Additional Precordial Leads

Lead V_3R: *This is the lead taken in the right fourth intercostal space* in the parasternal line and is similar in position to V_3 except that it is placed on the right side of the chest. This lead has proved of value in the diagnosis of right ventricular hypertrophy,[13,131] right bundle-branch block and in anteroseptal infarction.[133]

Normally this lead resembles Leads V_1 and V_2. An initial small r wave which represents potentials from the interventricular septum and the lateral wall of the right ventricle is followed by a large S wave representing

activation of the left ventricle. There is no deviation of the RS-T segment; the T wave may be upright, isoelectric or inverted; the P wave is diphasic or upright; at times it is isoelectric.

In right ventricular hypertrophy, the initial septal r wave is small and this is followed by a small W wave and a tall R′ wave. The latter represents activation of the lateral wall of the hypertrophied right ventricle. The T wave is usually isoelectric or inverted and there may be slight RS-T segment depression. The duration of the QRS complex is within normal limits. In cases of right ventricular hypertrophy where there is counterclockwise rotation on the long axis and the transitional zone is displaced to the right, Leads V_1 and V_2 may give no indication of the conditions present and V_3R will show a tall R′ wave.

At times this lead faces the right side of the interventricular septum; where Leads V_1 and V_2 fail to show an initial septal R, Lead V_3R will show this wave to be present.

In right bundle-branch block there is observed a small R and a small S wave followed by a notched, widened, and late R′ wave which is usually not as tall as that seen in right ventricular hypertrophy. The QRS complex is 0.12 second or more. The RS-T segment is depressed and the T wave is inverted.

High Precordial Leads: In addition to the placement of the precordial leads mentioned above, it has been shown by Wilson and associates,[121] Klein and Myers[134] and others that infarction of the mid- or upper portion of the lateral wall of the left ventricle may be missed by the usual precordial leads, but may be picked up by leads taken in positions $V_{3,4,5,6}$ in the third interspace. Klein and Myers[134] have recently observed a large series of cases in which leads taken in these positions were of value in such instances. In cases of suspected myocardial infarction in which the limb and precordial leads are negative or equivocal, it is suggested that such leads be taken. It should be pointed out that these leads record a portion of the lateral wall which lies between the portion recorded on the left precordial leads, and the one traced on aV_L, and therefore tap an area which is otherwise not recorded by the routinely taken precordial leads.

The Ensiform Lead V_E: The use of an ensiform lead V_E placed over the lower end of the xiphoid cartilage has been suggested by Wilson and associates.[121] Alvarez[135] analyzed the configuration of 100 ensiform leads and is of the opinion that this electrode registers potential variations of the free wall of the right ventricle and of the adjacent interventricular septum. The electrocardiographic pattern is similar to that obtained from other right ventricular regions. Deviations from the normal have been observed in posteroinferior infarction and in infarction of the right ventricle.

Significance of Tall R Waves in the Right Precordial Leads

Considerable interest has developed recently in the significance of tall R waves in the right precordial leads. This deflection may be relatively increased in amplitude as compared to the succeeding S wave and/or may be absolutely enlarged, notched and of increased duration (0.04 second or

over). Recently it has been found that this prominent wave may be the only significant evidence of posterior or posterobasal infarction. Because of the significance of this deflection, it has become of importance to review the causes of prominent R waves in this region. Tall R waves in the right precordial leads may be observed in (1) normal infants and children, (2) young adults with electrically vertical hearts, (3) right ventricular hypertrophy, (4) posterior and posterolateral myocardial infarction, and (5) right bundle-branch block.

Normal Infants and Children: The pattern of precordial leads in normal infants and children (Fig. 171 *A*) differs from that of adults with respect to the ratio of R to S waves in the right precordial leads and in the direction of the T waves. In infants and children the R wave in leads V_{3R} and V_1 is normally relatively much taller than those seen in adults and may equal or exceed the amplitude of the S wave. The T waves, in infants and young children, may be inverted to the V_3 and V_4 positions (juvenile pattern). The difference in electrocardiographic patterns may be the result of the following difference between the infant and the adult· in the infant there is (1) a greater cardiac·total body mass ratio; (2) a more globular shape of the heart and greater proximity of the heart to the exploring electrodes; (3) greater elevation of the diaphragm; and (4) a larger ratio between the thickness of the right and left ventricular free wall.[168] Of all the factors mentioned, the last is the most important.

Owing to the relatively thicker right ventricular wall in children, the electrical forces of activation are oriented to the right and anteriorly (the position of the right ventricle). Since the lead axes of Leads V_1 and V_{3R} are so positioned that they are parallel to the direction of these forces, the amplitude of the upright deflection will be increased in these leads.

Young Adults with Electrically Vertical Hearts: In patients with electrocardiographically vertical cardiac position (Fig 171 *B*) the potentials are directed primarily inferiorly to the left and anteriorly. The anterior orientation of these potentials may frequently produce increased potentials in the leads, the axis of which is in the direction of these forces (V_{3R} and V_1).

Right Ventricular Hypertrophy: Normally the ratio of left to right ventricular mass is 1.8:1.0. With right ventricular hypertrophy (Fig. 171 *C*) this ratio is altered in favor of the right ventricular mass. As stated before, normally the recorded electrical potential is directed to the left, posteriorly and inferiorly, because this is the location of the predominant left ventricle. When this predominance is diminished or reversed by an abnormal process which enlarges the right ventricle, the forces tend to reverse their orientation into the direction of the abnormally predominant right ventricle, *i. e.*, anteriorly and to the right.[169] Such potentials are expressed by large positive deflections in the leads with lead axes parallel to these forces: V_{3R} and V_1.

Posterior and Posterolateral Myocardial Infarction: The present concept of myocardial infarction (Fig. 171 *D*) will be discussed. Large R waves in leads V_{3R} and V_1 are frequently seen in patients with myocardial infarction of the posterobasal wall. This is due to loss of potential in the

infarcted area, enhancing the normally weaker anterior potentials which are now unopposed.

Right Bundle-Branch Block: With the adoption of the routine practice of recording a complete unipolar chest lead electrocardiogram, an rSR′ pattern in the right precordial leads is frequently observed. This pattern has been seen in patients with a clinically normal heart; however, it has been observed even more frequently in patients with myocardial disease and/or cor pulmonale, and not uncommonly in patients with congenital heart disease associated with right ventricular hypertrophy. The pattern consists of an rSR′ complex recorded in Leads V_{3R} and V_1 in which the late positive deflection (R′) is tall and occasionally widened and slurred, so that the total duration of the QRS complex varies from 0.09 to 0.16 second. The slurred R′ wave and the late intrinsicoid deflection from the right precordial leads are distinctive features of this pattern. The extremity leads are characterized by a wide S wave in Lead I and a wide R′ in V_R.

A study of the electrocardiograms in Figure 172, *A* and *B*, reveals similar patterns with regard to form and electrocardiographic position. In *A*, in a patient with congenital heart disease and associated right ventricular hypertrophy, the wide R′ in V_{3R} and aV_R and the wide S in Lead I are the result of the reversal of the normal electrical forces, so that the electrical forces are oriented to the right, anteriorly and inferiorly. In addition, there is delayed conduction in the hypertrophied right ventricle which is oriented in the same direction; this pattern constitutes the classical type[170] of right bundle-branch block and, with the addition of delay in conduction, is similar in genesis and form to the pattern of right ventricular hypertrophy already described.

In 1938 Wilson and Johnston[171] recorded the spatial vectorcardiogram of two patients with the electrocardiographic pattern shown in Figure 172, *B*. Since that time the vectorcardiographic pattern[170] has been found to be quite distinctive. In this condition the initial and major portion of the QRS forces have a normal orientation and direction of rotation. The late positivity over the right precordium, which gives rise to the wide R′ in V_{3R}, V_1 and aV_R, with a wide S wave in Lead I, is associated with the presence of an abnormal, slowly progressive appendage which is oriented to the right and anteriorly. This pattern is known as the Wilson type of right bundle-branch block. However, it must be noted that there is no specific abnormality of the conduction system and that the recorded electrocardiogram giving rise to this pattern is similar in form to that of classical right bundle-branch block. The Wilson type of right bundle-branch block pattern is the result fo a localized delay in conduction which is oriented in space to the right and anteriorly.

Ventricular Hypertrophy

The correlation between left and right axis deviation, in the limb leads, and actual ventricular hypertrophy is not very clear. Left and right axis deviation may exist in the electrocardiogram without actual ventricular hypertrophy. Conversely, ventricular hypertrophy may be present without

corresponding axis deviation in the electrocardiogram.[112] In some instances, too, left ventricular hypertrophy may exist while the electrocardiogram yields a right axis deviation (vertically placed heart), and in right

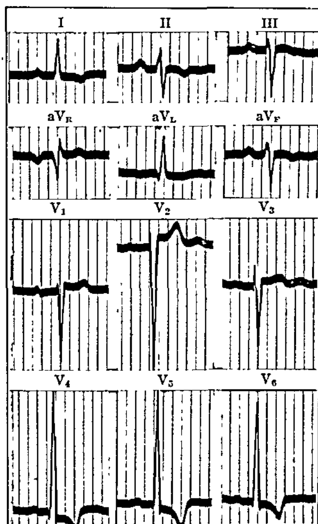


FIGURE 40 Left ventricular hypertrophy with heart in horizontal position. Lead aV_L represents left ventricular potentials, while Lead aV_F resembles V_1 and V_2 This rep[illegible] between [illegible] shows a [illegible] at the b[illegible] apex backward on a transverse axis The T waves are inverted in Lead I and the left precordial leads V_4, V_5 and V_6

ventricular hypertrophy a left axis deviation may be obtained if the heart is transversely placed.

The pattern of the ventricular complexes in hypertrophy is a more exact one in the precordial leads.[121, 13] If one uses chest rather than the limb leads, definite preponderant hypertrophy of one ventricle can, in most

cases, be positively recognized. This is due to the fact that where one ventricular wall is thicker than it should normally be and the other is not, the electrical impulse will require longer to traverse the thicker wall than the thinner wall of the other ventricle. In left ventricular hypertrophy, the electrical impulse denoted by the peak of the R wave (intrinsicoid deflection) arrives late in the left side of the heart, as compared to the

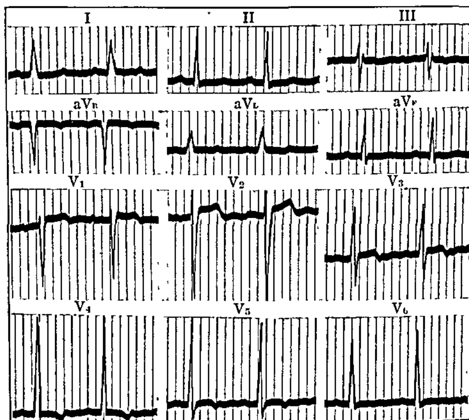


FIGURE 41. Left ventricular hypertrophy with heart in semivertical position Lead aV_F resembles Lead V_6, while Lead aV_L has no counterpart in the precordial leads This represents a semivertical position with regard to the antero- [illegible] V_3 so [illegible] ives [illegible] ver- [illegible] tion [illegible] on the anteroposterior axis

normal, and in right ventricular hypertrophy the electrical impulse or intrinsic deflection arrives late in the right side of the heart as compared to the normal.

Specifically, when left ventricular hypertrophy is present, the impulse will take longer to traverse the thickened left ventricular wall than the unhypertrophied right ventricular wall. Consequently, the peak of the R wave will occur later, after the beginning of the QRS complex, in those leads in which the exploring electrode is situated over the left ventricle

(*e. g.*, V_5). The peak of the R wave will be definitely nearer the beginning of the QRS complex in those leads in which the exploring electrode is situated over the right ventricle (*e. g.*, V_1, V_2, and V_3). The reverse will be the case in right ventricular hypertrophy. The peak of the R wave will be farther from the beginning of the QRS complexes in Leads V_1, V_2, and V_3, than it is in Leads V_4, V_5, and V_6.

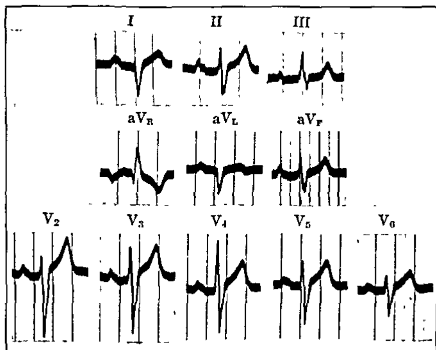


FIGURE 42 Right ventricular hypertrophy and marked clockwise rotation in a vertical heart, from a patient with congenital pulmonic stenosis Marked right axis deviation is present in the limb leads There is a late, broad R wave in aV_R which represents activation of the lateral wall of the hypertrophied right ventricle. There is a prominent S wave in all of the precordial leads, and the transitional zone is probably in the left posterior axilla or in the left side of the chest posteriorly

The electrocardiographic patterns in precordial leads of normal subjects and in persons with ventricular hypertrophy have been described by Wilson and his associates,[121] Kossman and associates[131] and Myers and associates.[13] In normal subjects, the ventricular complexes of precordial electrocardiograms are characterized on the right side of the precordium by a small R deflection and relatively deep S deflections.[107,121] The peak of the R, which represents the arrival of the impulse at the epicardial surface, appears early. The ventricular complexes in the leads from the left side of the precordium show tall R waves. The complexes are relatively wide and occasionally are preceded by a Q and followed by an S deflection. The peak of the R is about 0 02 second later on the left than in leads from the right side of the precordium. Between the leads from the right and left side of the precordium Leads C_3 and C_4 show complexes of an intermediate

type to those just described. This zone varies from subject to subject and depends, to a large degree, upon the shape of the heart. The range of values of the QRS and T deflections in the various precordial leads have been described by Kossman and Johnston.[107]

Diagnosis of Left Ventricular Hypertrophy. ***Limb Leads:*** The findings in the limb leads depend upon the position of the heart and the degree of

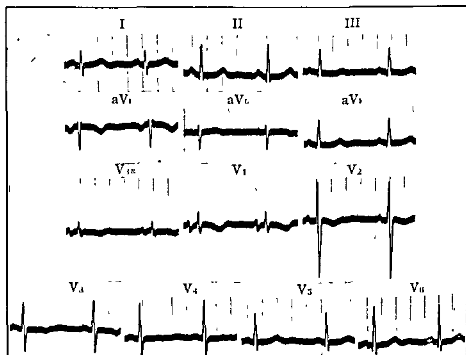


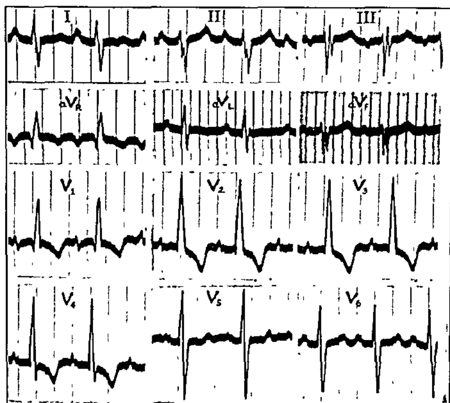
FIGURE 43 Right ventricular hypertrophy in a vertical heart Lead I shows a [illegible]

a patient with mitral stenosis and a moderate degree of right ventricular hypertrophy

hypertrophy: (1) They usually show left axis deviation frequently with a deep S wave in Leads II and III. Occasionally no axis deviation or a right axis deviation may be observed in the presence of a ptotic heart. (2) The QRS complexes are top normal in width (up to 0.11 second). (3) The amplitude of QRS in Leads I and III is frequently increased up to 20 mm. or more. (4) The T waves in Lead I are diminished in amplitude, later flattened and finally inverted; occasional depression of the RS-T segment in Lead I and elevation in Lead III are often observed.

Precordial Leads: (1) The voltage of the chief deflections of the QRS group is much greater than normal; the R wave in V_5 or V_6 often exceeds 26 mm. (2) The QRS interval is increased to 0.10 or 0.11 second. (3) The onset of the intrinsicoid deflection (the ventricular-activation time) ex-

ceeds 0.05 second in V_5 and V_6. (4) In leads from the right side of the precordium, the R deflections are on the average smaller than normal and are occasionally absent, and the transitional zone is as a rule much displaced to the left. (5) In early cases, the T wave in V_5 or V_6 may be low, flat, or diphasic, in association with depression of the RS-T segment. Later symmetric inversion of the T wave is observed in V_5 or V_6 with a depressed RS-T segment.



FIGU... in lim... the pr... the T... in V_1... auricular septal defect and marked right ventricular hypertrophy

Unipolar Limb Leads: The same characteristics noted in V_5 and V_6 often appear in aV_L in horizontal hearts and in aV_F in vertical hearts The abnormalities seen in aV_L are usually more striking than those found in Lead I.

Diagnosis of Right Ventricular Hypertrophy. ***Limb Leads:*** (1) A right axis deviation is present. (2) The QRS complexes are frequently increased in amplitude, particularly in congenital hearts. (3) The T waves in Leads II and III are sometimes inverted (4) A small Q_3 is frequently present.

(5) Occasionally, incomplete or complete right bundle-branch block may be observed.

Precordial Leads: (1) Reversal of the normal ratio in the amplitude of the R and S waves in V_1 and V_6, characterized by an abnormally large R in proportion to S in V_1, a diminution in ratio in leads farther to the left, and a prominent S in V_6. (2) In certain cases with marked clockwise rotation, the R waves may be small in V_1 to V_4, the transitional zone being

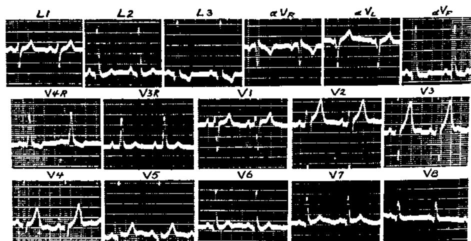


FIGURE 45 Additional precordial leads to the right (V_{3R}-V_{4R}) in right ventricular hypertrophy J. H, white male, aged eighteen years. Congenital pulmonary valvular stenosis The conventional ECG with standard and unipolar limb leads and six (V_1-V_6) unipolar precordial leads could be interpreted as an electrically vertical heart within normal limits Note that in leads V_{3R} and V_{4R} the QRS complex is predominantly upright and of considerable amplitude (an indication that the QRS forces are oriented anteriorly and somewhat to the right) and are considered to be evidence of right ventricular hypertrophy

shifted to V_4 or V_5. (3) The time interval from beginning of QRS to onset of intrinsicoid inflection was abnormally long in V_1 (0.3 to 0.5 second) and greater than in V_5 or V_6. (4) Frequent small Q waves in V_1. (5) Frequent inversion of the T wave in V_1 with tendency to become upright in V_5 or [illegible] occasionally a [illegible] of V_1 [illegible] pattern in V_3R (tall R wave). (9) Incomplete bundle-branch block. (10) Occasionally complete bundle-branch block.

Unipolar Limb Leads: (1) May show normal basic ventricular patterns. (2) Signs of auricular hypertrophy may appear in one of the unipolar extremity leads (increased amplitude of P wave). (3) Marked clockwise rotation of the heart may be present. (4) A tall R wave in aV_R which may be four to ten times the amplitude of a downward deflection in the same lead. (5) Finally, the presence of right bundle-branch block. Occasionally, particularly in the early stages, right ventricular hypertrophy may be present without electrocardiographic changes.

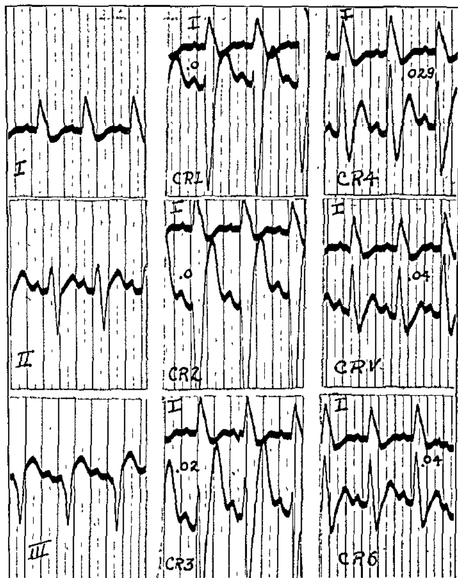


FIGURE 46 Left bundle-branch block Precordial Leads CR_1 to CR_5 are taken synchronously with a Lead I Note widened QRS complexes, small R waves until the CR_4 position. Note delay of onset of intrinsicoid deflection on the left side in CR_5 and CR_6 position

Bundle-Branch Block

Bundle-branch block may be partial or complete. It may involve either the main right or left or both branches, occasionally, it may result from extensive involvement of smaller branches. Bundle-branch block is usually observed in patients with rheumatic or syphilitic aortic valvular disease, hypertensive heart disease, coronary arteriosclerosis and as the result of certain drugs, particularly quinidine. The diagnosis of established bundle-branch block should not be made if the ventricular rate is rapid (120 to 160 per minute), since it may be due in this case to temporary fatigue

of the conducting tissue. With the resumption of a slow rate, the intraventricular conduction may return to normal. The Wolff-White-Parkinson syndrome (short PR interval and widened QRS complexes) is not true bundle-branch block and does not have the same pathological significance.

The site of the lesion in bundle-branch block, whether right or left, is best determined by the use of serial precordial leads, CR_1 to CR_5, sometimes with the synchronous recording of Lead I, to determine if the delay is on the right or left side of the heart. While widened QRS complexes in the presence of a left axis deviation are usually associated with left bundle-branch block, in vertically placed hearts a right axis deviation may be present in the limb leads and the site of the lesion, as clearly shown in the precordial leads, may be the left bundle branch. The reverse is true, as regards right bundle-branch block, in the presence of left axis deviation with the heart in the transverse position.[110,121]

In general, it may be stated that when the QRS interval measures 0.12 second or more and the QRS complex is widened in Lead I and consists of a broad or bifid R deflection, with or without the presence of left axis deviation, the precordial curves are usually characteristic of left bundle-branch block. When the QRS interval measures 0.12 second or more and the QRS complex in Lead I is biphasic or triphasic and ends with a broad, slurred or arched S deflection, the precordial curves are usually characteristic of right bundle-branch block.[121]

In right bundle-branch block, the R waves of the chest leads are of considerable amplitude on the right side of the precordium, and the peak of the R wave occurs late. The R wave is of considerable amplitude in the left side of the precordium (V_5 position) but the intrinsicoid deflection is not delayed (Fig. 49).

In left bundle-branch block the peaks of the R waves are small and occur relatively early on the right side of the precordium (V_1 position) but occur late on the left side of the precordium (V_5 position). The R waves remain small until the left side of the precordium is reached (V_5 position); *i. e.*, the transitional zone is shifted to the left (Fig. 46).

Left Bundle-Branch Block: In left bundle-branch block, the right side of the interventricular septum is the first region of the heart that is stimulated. The initial spread of the impulse from right to left is recorded as an initial upward deflection by leads that face the epicardial surface of the left ventricle, and as an initial downward deflection by leads that face the right side of the septum. In leads that face the epicardial surface of the right ventricle, the final spread of the stimulus to the left ventricle causes another downward deflection before the initial downward deflection can rise to the base line and a deep wide-notched deflection occurs. In leads that face the epicardial surface of the left ventricle, before the deflection can reach the base line the stimulus which has begun to spread through the larger left ventricle counterbalances this and causes another upward deflection.

Leads that face the epicardial surface of the right ventricle (V_1, V_2, and V_3) frequently show a small R wave that precedes the S wave. The small R waves are probably due to an early spread of the stimulus to the right

ventricular wall in the region of the apex of the heart. Leads that face the epicardial surface of the left ventricle (V_5 or V_6) show a tall R wave. Leads that show a wide-notched R are usually associated with a depressed RS-T and a downward T. Leads that show a wide S wave are usually associated with an elevated RS-T and an upward T.

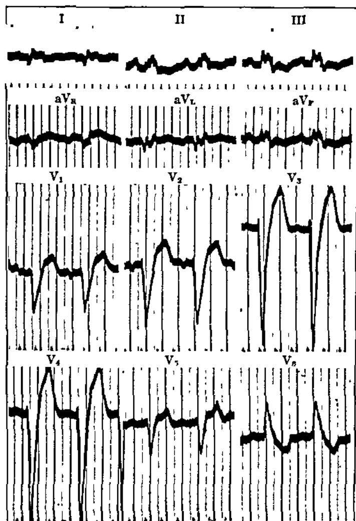


FIGURE 47 Left bundle-branch block in a patient with vertical position of the heart The QRS complexes are slurred, notched and widened in all of the leads A Q wave is present in Leads I and aV_L. The precordial leads show small R waves and deep, broad S waves until V_6, where a tall, late slurred R wave and an inverted T wave are found The transitional zone is between V_5 and V_6

The time of onset of the intrinsicoid deflection in precordial leads facing the epicardial surface of the left ventricle, such as V_5, V_6, is delayed to 0.09 or 0.10 second, in contrast to a maximum normal time of onset of the intrinsicoid deflection in these leads of 0.04 second. This delay is due to the slow spread of the stimulus through the affected left ventricle

The unipolar extremity leads vary with the position of the heart. When the heart is vertical, the aV_F usually shows a tall, wide R wave without a Q. When the heart is horizontal, Lead aV_L shows a tall wide R wave without a Q.

Incomplete Left Bundle-Branch Block: The diagnosis of *incomplete left bundle-branch block* is very difficult. The difficulty lies in the fact that

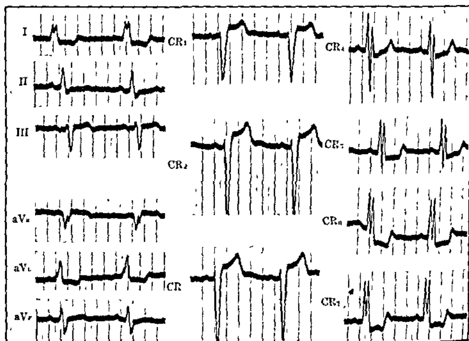


FIGURE 48. Left bundle-branch block in a heart whose electrical position is semi-

in left bundle-branch block the septal and mural components of the upward deflection from points over the left ventricle are not separated and therefore the complexes cannot be distinguished from those in many cases of left ventricular hypertrophy. The diagnosis can be excluded when there is a Q wave in one or more of the precordial leads from the left side of the precordium, since this indicates left to right activation of the septum. Some authors use the term when the precordial leads show the typical pattern of left bundle-branch block, but the QRS complex is only 0.10 second in width.

Precordial and Unipolar Limb Leads in Right Bundle-Branch Block: When right bundle-branch block occurs, the left side of the septum is the first part of the ventricles to be activated as in the normal. The stimulus, therefore, spreads through the septum from left to right. This causes the unipolar leads that face the epicardial surface of the right ventricle to record an upward initial deflection. Leads that face the epicardial surface

of the left ventricle record this initial electrical activity as a downward deflection. As the stimulus spreads through the left ventricle, its direction is opposite to that through the septum; this tends to counterbalance the amplitude of these individual deflections They are therefore decreased.

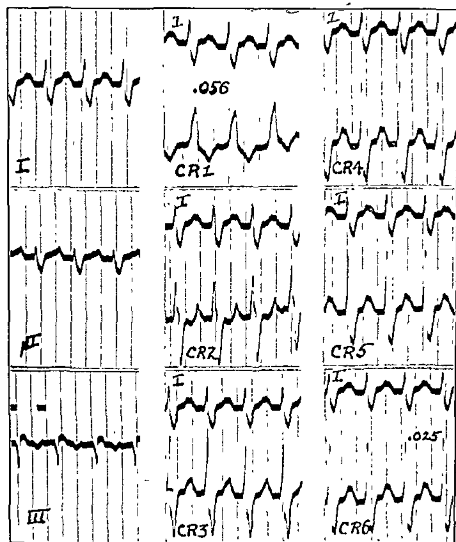


FIGURE 49. Right bundle-branch block Precordial Leads CR_1 to CR_6 are taken simultaneously with Lead I Note widened QRS complexes with tendency to right axis deviation in limb leads Note presence of R waves with no S waves in CR_1 position and that even up to C_6 position, the R wave is more prominent than the S wave Note delay of onset of intrinsicoid deflection on the right side with no delay on the left side

When the septum is completely stimulated, the deflection tends to return to the base line, but the spread of the stimulus to the left ventricle at this time causes leads that face the epicardial surface of the right ventricle to record a downstroke. When the left ventricle is completely stimulated, the

deflection tends to return to the base line again. But the stimulus that is slowly passing outward through the right ventricular wall causes leads that face the epicardial surface of the right ventricle to record a wide final upstroke. In the presence of right bundle-branch block, leads that face the epicardial surface of the affected right ventricle show a wide rsR. Leads that face the epicardial surface of the normal left ventricle show a wide qRS pattern (Fig. 49).

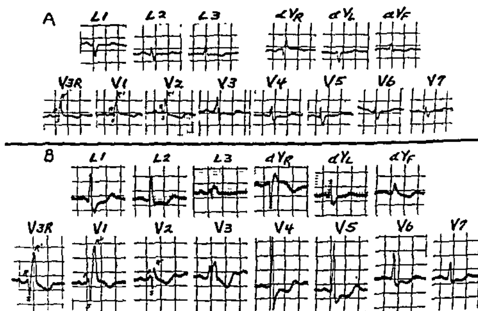


FIGURE 50 Right bundle-branch block. Examples of electrocardiograms *A*, White female, age twenty-three years; congenital interatrial septal defect, right ventricular hypertrophy. Note the wide S waves in Leads I, II, aV_L, and V_4 to V_7; and the late, wide R wave in Leads aV_R, V_{3R}, and V_1. This is an example of classical right bundle-branch block. *B*, White male, age thirty-two years; clinically normal heart Note that the wide R and S waves have the same distribution as noted above A vectorcardiogram showed no change from the normal in direction of rotation of the major portion of the QRS loop, an example of the "Wilson type" of right bundle-branch block.

The slow spread of the stimulus through the right ventricular wall and septum causes a prolongation and widening of the QRS complex to 0.12 second or more. The intrinsicoid deflection in V_1 occurs late when right bundle-branch block is present. This may occur as late as 0.07 to 0.08 second in contrast to the maximum normal time of 0.03 second.

The unipolar extremity leads and the standard leads vary with the position of the heart.

Incomplete Right Bundle-Branch Block: The term "incomplete right bundle-branch block" can be used when precordial Lead V_1 shows an rsR' with a wide R', and Lead V_5 or V_6 shows a qRS, with a wide final S, but the QRS interval is less than 0.12 second. The intrinsicoid deflection in V_1 is between 0.05 and 0.075 second. This is greater than normal and that found in right ventricular hypertrophy, but less than that found in typical right bundle-branch block (Fig. 76).

Focal Bundle-Branch Block (Focal Intraventricular Block): Focal bundle-branch block is considered to be a rare condition which can only be diagnosed when multiple precordial leads are used. Under these circumstances the electrical field set up by this area of block is so small that only when electrodes are placed very close to it does it reveal itself. When this situation is present, the QRS width will be of normal duration in the standard leads as well as in all the precordial leads, except in that one over the involved area in which the QRS duration will be longer than 0.12 second. In those cases reported the right bundle is the one involved, in all probability owing to the fact that it is more vulnerable to such localized lesions since it branches profusely soon after it divides from the common bundle. This type of block may be found in hypertrophied hearts as a result of fibrosis or secondary to ventricular hypertrophy or in cases of coronary insufficiency where diffuse fibrosis is present.[152]

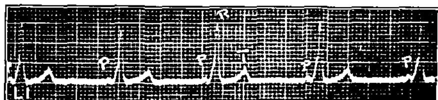


FIGURE 51 Short PR intervals with widened QRS complexes (Wolff-White-Parkinson syndrome): This combination of findings is not very common, but is seen in apparently entirely healthy individuals Auricular paroxysmal tachycardia is a very frequent accompaniment

SHORT PR WITH PROLONGED QRS COMPLEX (WOLFF-WHITE-PARKINSON SYNDROME)

The Wolff-White-Parkinson syndrome is characterized by a short PR interval measuring 0.10 second or less and QRS 0.11 second or longer. The P wave *is upright and the QRS prolongation and notching affect the first* part of the deflection. The phenomenon is due to a congenital anomaly in which, in addition to the normal passage of the cardiac impulse from auricle to ventricle, an accessory pathway connecting the lateral wall of the right auricle and ventricle (bundle of Kent) or a muscular bridge located elsewhere is present. Such accessory pathways have been demonstrated at necropsy by serial sections. When an accessory pathway is present, and the impulse is blocked through the AV node, a short PR interval with a widened QRS complex will appear. When the impulse is blocked in the accessory pathway, a normal PR and QRS will be observed. The prolongation of the QRS complex is explained in the following manner: (1) *The accessory pathway is located at a distance from the normal* AV junction and does not connect with the AV bundle fibers so that the impulse spreads in an abnormal manner through the ventricles; (2) the accessory pathway is located close to, and connects with the common AV bundle but the sinus impulse in passing to the ventricles splits in two: one travels through the AV node and the other by-passes it. In this case the

pathway by-passing the AV node will reach the ventricles earlier and thus shorten the PR interval, and the asynchronous arrival of the two impulses in the ventricles will lead to a fusion beat in which the prolongation in the QRS will be in proportion to the asynchronism of the two impulses.

The importance of recognizing this condition is in the fact that it may occur in an otherwise normal heart although its presence does not preclude organic heart disease. Katz[126] has found that fifty per cent of persons with this abnormality have organic heart damage. Finally, patients with this syndrome are susceptible to the development of paroxysmal auricular tachycardia and occasionally paroxysmal auricular fibrillation and paroxysmal ventricular tachycardia.

This syndrome may be produced by carotid sinus stimulation, by digitalis or cholinergic substances (prostigmine, mecholyl). Exercise, atropine, and quinidine may abolish it.

MYOCARDIAL INFARCTION

Since Herrick[63] placed the diagnosis of coronary artery occlusion on a firm clinical basis, a number of gradually accumulating observations have given the electrocardiogram a prominent place in the study of this important condition. Among these, the experimental work of F. M. Smith[64] and that of Pardee,[65] Parkinson and Bedford,[66] and Barnes and Whitten[67] deserve special mention. Since 1932, the diagnostic possibilities of the electrocardiogram have been markedly increased by the use of the precordial leads, the value and importance of which have been clearly shown by the work of Wolferth and Wood[3] and that of Wilson.[4] By the combined use of the limb and precordial leads, the diagnosis of myocardial infarction can now be made by the electrocardiogram in over ninety per cent of cases. In addition, the site of the infarcted area can usually be definitely determined and the course of healing can be followed by the careful use of the electrocardiograph.

Determination of the site and size of infarction is important in prognosis. Patients with posterior or lateral infarction usually present a better outlook than those with anterior myocardial infarction and usually require a relatively shorter period of bed rest.

Pathologic Physiology

The earliest evidence of a pathological process observed in animals in which an infarct is produced experimentally is sharply inverted T waves in the direct epicardial leads. This phenomenon is rarely seen in the precordial leads employed in man. The next change is RS-T segment deviation, both in animals and in humans. The exact pathogenesis of this change is unknown. The classic explanation is as follows: The interior of the muscle cell is negatively charged, and the exterior is positively charged. Therefore, in the uninjured resting cell a constant potential difference exists between the inside and outside of the cell. When the cell is injured, this potential difference is altered so that it is more negative with respect to an indifferent electrode, and a "current of injury" is said to flow when the muscle is in the polarized state. This displaces the string of the galva-

nometer downward, but since it is a constant current it is corrected for by the electrocardiograph. After depolarization and before repolarization, however, no such negative influence with respect to the rest of the muscle exists, since now the heart has no charge at all. The correction currents from the machine then overcorrect and serve to elevate the base line during the isoelectric period, and therefore produce elevation of the RS-T segment.

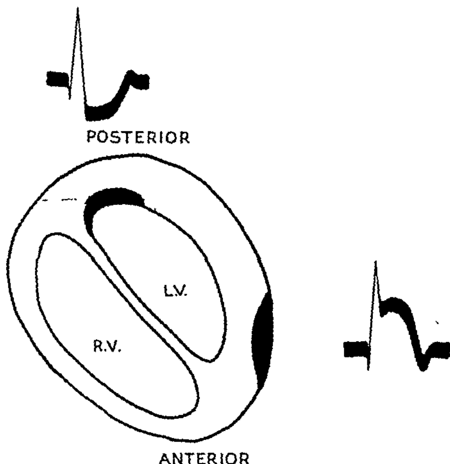


FIGURE 5[illegible]. Diagrammatic representation of transection of heart, showing effect

This theory is somewhat difficult to maintain in the face of the newer unipolar leads, and it has recently been postulated that the RS-T deviation may be due to altered time relationships between repolarization in healthy and injured muscle. Whether or not this is correct, it is an empirical fact that when the exploring electrode is placed over recently injured muscle it inscribes an elevated RS-T segment. It is also an em-

pirical fact that the RS-T segments are depressed if a layer of uninjured muscle lies between the exploring electrode and the injured area.

The RS-T elevation is usually a short-lived sign of injury and disappears within hours or days, probably because the injured muscle either recovers or dies, and therefore ceases to introduce extrinsic currents or imbalances. Maintained RS-T segment deviation spells complications.

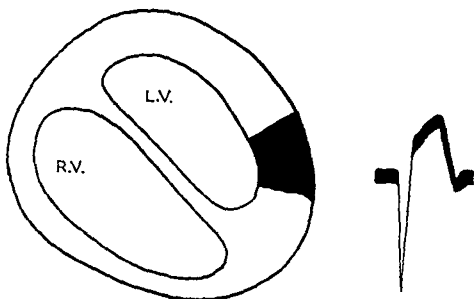


FIGURE 53 Same as Fig. 52, showing effect of transmural infarct on the epicardial lead taken over the infarcted region on the anterior wall The RS-T segment is elevated owing to the acute injury, and the initial upper deflection is absent because this electrode is tapping the endocardial potential.

They consist of either extension of the injured area or ventricular aneurysm and carry an ominous prognosis.

As the RS-T deviation returns to normal, two changes take place, both in experimental animals and in man: (1) The QRS complex begins to show the characteristic and often permanent signs of injury, and (2) the T waves begin to invert.

1. Normal endocardial potential is negative in sign, and the epicardial charge is positive. When the heart muscle is injured severely enough so that it dies from the endocardium through to the epicardium, this potential difference can no longer be maintained, and the electrode applied over the dead area records endocardial potential; namely, negativity. Over the dead muscle a QS deflection is therefore inscribed when the endocardium is negative (Fig. 48). If the muscle is not quite infarcted through and through, and a healthy portion of epicardial muscle is maintained, a deep wide Q wave is inscribed, with a short abortive R (positive) deflection. It should be mentioned here that in spite of the extensive injury the QRS complex may not be widened. The explanation for this is obscure, but it is generally assumed that the surrounding healthy fibers conduct the impulse to the epicardium or that, although dead and unable to produce potential, the injured muscle cell may be as good a conductor as the nor-

mal cell. Sometimes the QRS is widened, however. The Q waves due to dead muscle must not be confused with the normal Q waves seen over the left ventricle, which are due to the early activation of the left side of the septum.

2. The pathogenesis of the inverted T wave of myocardial injury has been a much-studied phenomenon. As with RS-T deviation, it is generally thought to be due to an imbalance of the time relationship of repolarization of healthy and injured muscle. The shape of the inverted T wave is often characteristic, and the temporal change of its configuration is taken as a guide to the disease process.

Pathologic Considerations

Coronary occlusion is most apt to occur in either one of two sites—in the anterior descending branch of the left coronary artery, 1 to 1 5 cm. from its orifice, or in the right coronary artery. Closure of the right coronary artery occurs near its orifice but more often near the crus where the right circumflex artery turns to become the posterior descending branch of the right coronary artery.

Immediately following the occlusion, the normal electrical excitation is disturbed in the damaged muscle and is replaced by abnormal currents which occur in injured muscle. These are called currents of injury and produce the characteristic change in the electrocardiogram, namely, deviation of the RS-T segment and T wave changes At varying periods following the occlusion, irreversible changes appear in the heart muscle: Myocardial infarction takes place and reaches its maximum extent 24 to 48 hours after the acute occlusion or even later, depending on the type and character of the occlusion. If the patient survives, this is followed by a period during which the process of infarction merge into a subacute phase where many of the acute features subside. It is difficult to give accurately the length of the acute and subacute stage in human cases, however, judging from the sequence of events in dogs and relating these to serial electrocardiograms and postmortem findings in humans, *it appears that, in the usual case, the acute and subacute stages have an average of two to three weeks' duration in posterior and three to five weeks' duration in anterior infarctions.* This varies greatly in different cases. At necropsy, one often observes healing in one portion and evidence of acute and subacute infarction in another portion of the involved area.

Strictly speaking, the electrocardiographic changes are not the result of coronary occlusion. The electrocardiogram records evidence of acute muscle damage resulting from the occlusion. While currents of injury are usually the result of myocardial infarction, they may be produced by other causes, *e. g.*, inflammatory involvement of the myocardium in pericarditis, acute rheumatic myocarditis and anoxia. However, certain other characteristics in the electrocardiographic pattern usually enable one to decide if the currents of injury are the result of myocardial infarction or are produced by some other cause

Size of Infarcted Region: The electrocardiographic alterations depend not only upon the location but upon the size of the infarcted area. The size of the region infarcted depends upon many factors·

1. The *size of the vessel* occluded: Since considerable variation exists anatomically in the size and distribution of various branches of the coronary arteries, occlusion of the same vessel in different hearts does not necessarily give rise to areas of infarction similar in extent. To mention but a few examples of such variations: (*a*) The right coronary artery is occasionally a much smaller vessel than is usually observed, and in this case a portion of the area supplied by this artery is taken over by the circumflex branch of the left coronary. (*b*) The upper lateral wall of the left ventricle generally supplied by the circumflex branch of the left coronary artery is, in ten per cent of hearts, replaced by a large circumflex branch of the right coronary artery. (*c*) Considerable variation exists in size and number of the lateral branches of the anterior descending branch of the left coronary artery and their manner of branching.

2. The *mode of formation and size* of the thrombus: Closure may develop slowly permitting opportunity for neighboring vessels to supply the infarcted area. The thrombus may be small (0.5 to 1 cm.), thus allowing the occluded artery to function by its connections to neighboring vessels. An initially small thrombus may gradually or rapidly extend, ultimately involving the entire vessel and thus depriving a considerably greater area of its blood supply.

3. The *thrombus may be single or it may be preceded by previous thrombi* in the same vessel; the vessel itself may have previously been the seat of arteriosclerotic narrowing at one or more points.

4 The *age of the patient* is of some importance: Closure of a coronary artery in a relatively young person is said to carry with it a more serious prognosis than in an older patient, owing to the presence of more anastomotic channels in the latter and the inability of arteriosclerotic vessels to develop a spastic closure of their lumina.

5. The occurrence of *spasm** in the remaining coronary arteries following an acute occlusion[68] is an important factor in determining the extent of the infarcted area and ultimately the patient's survival. This spastic factor would not be as important in the presence of arteriosclerotic coronary arteries since these cannot so readily go into spasm.

6. The factor of *cardiac rest* includes the rapidity with which complete physical and mental rest is secured following the occlusion. The continuance of the patient at work and the withholding of analgesics and sedatives during periods of pain increase the work of the heart and would tend to increase the size of the involved area and delay healing. The same is true if a rapid ectopic rhythm develops following a coronary occlusion; this would tend to decrease the coronary flow while at the same time increasing the work of the heart.

7. The presence of *new areas of infarction* gradually forming during the process of healing of the original process may prolong the acute and subacute stages to two to three months or longer.

* It is very difficult to [illegible] since there are no vaso- [illegible] coro- [illegible] output [illegible] due to [illegible]

8. The *previous status of the coronary circulation* is of great importance. Many patients with coronary occlusion have two or more infarctions at various times. The occurrence, for example, of a posterior infarction after a previous anterior infarction increases the extent of the infarcted area in the former since a large portion of its possible anastomotic supply is cut off.

The Electrocardiogram in Myocardial Infarction

In view of the numerous variations in the type, progression and extent of myocardial infarction, it becomes apparent how markedly the electrocardiogram may vary. Many different patterns of myocardial infarction may be observed, depending on their location; for example, anterior, anterolateral, anteroseptal, high anterolateral, septal, posterior, posterolateral, and occasionally infarction of the right ventricle. The diagnosis of some of these is rather clear-cut; in others the electrocardiographic diagnosis is less certain. Before discussing the patterns in the various locations of infarction, it is of interest to indicate the factors that alter the initial phase of the ventricular complex.

During the evolution of the theory of electrocardiography the QS and QR complexes observed in myocardial infarction have been ascribed to various factors: (1) transmural infarction with the recording of endocardial potentials, (2) an initial R wave caused only by the epicardial portion of the myocardium rather than by the entire myocardium extending from endocardium to epicardium;[157] (3) on a purely vectorial basis, QS complexes are considered to be the result of loss of potentials in the infarcted area, thereby resulting in augmented (unbalanced) forces directed away from the exploring electrode (QS or QR instead of rS or RS). These points are now to be amplified.

A Q wave is said to be significant if it fulfills all or some of the following criteria: (1) width of 0.04 second and (2) a depth of twenty-five per cent or more of the succeeding R wave.

A significant Q wave is considered[158] to be the result of a transmural infarct in which the exploring electrode records endocardial potentials from the adjacent ventricular cavity, the so-called "electrical window." Some doubt has been cast upon this theory, however.

As the result of their experimental work, Prinzmetal and his associates,[157] by means of multiple intramural and intraseptal leads (plunge electrode), concluded that approximately eighty per cent of the ventricular musculature exhibited predominantly negative depolarization potentials (QS-Qr); positive potentials prevailed only in a relatively thin epicardial layer of the ventricular wall and in the middle and right side of the septum Burning or excision of the epicardial region of positivity drastically diminished the amplitude of the surface R wave or actually produced a surface QS wave.[157] These findings, coupled with the consistent absence of QRS abnormalities in tracings recorded over infarcts not involving the epicardial region, are believed to indicate that leads facing the intact epicardium yield a fairly accurate representation of epicardial potentials and do not reflect the status of the large mass of underlying intramural muscle. The clinical application of these findings is that "a coronary QS wave

may signify either uniform through *and through* muscle death, or inactivity of only the *epicardial zone* of positivity, or any intermediate amount of myocardial damage."[157]

[illegible] al potentials nor- [illegible] balance of forces ensues, so that the resultant electrical potential is altered in magnitude and, even more important, in direction. The forces developed in portions of the heart located opposite to the infarcted area are now no longer opposed, thereby displacing the final sum of forces away from the infarcted area. The orientation and magnitude of this new resultant force, infarction vector, are dependent upon the size and location of the infarcted area. The loss of electromotive forces, due to myocardial infarction with resultant electrically inert areas, not only alters the electrocardiogram recorded over that area, but also influences the pattern recorded distally, particularly that recorded directly opposite the inert area. The value of multiple precordial leads in determining this abnormal force is apparent. Infarction of the anterior wall will result in an initial force which is directed posteriorly. Precordial Leads V_2, V_3, and V_4 will therefore record a QS or Qr deflection; since this abnormal force is perpendicular to the frontal plane, there may be no abnormalities of the QRS complex in the bipolar or unipolar limb leads. Infarction of the inferior or diaphragmatic wall of the left ventricle will augment the new, initial forces of activation in a superior direction; the electrocardiogram will record a significant Q wave in Leads II, III, and aV_F; since the new resultant force is perpendicular to the horizontal plane, the precordial leads may show no abnormality of the QRS complex. This concept has recently been helpful in the recognition of infarcts localized to the posterior wall of the left ventricle. In such an infarct the new resultant forces are directed anteriorly and somewhat to the right; the right precordial leads record tall, wide (0.04 second or over) R waves followed by upright, symmetrical T waves, with or without RS-T segment depression; this is the mirror image of an anterior myocardial infarct. The importance of the recognition of this pattern is that in the standard twelve-lead electrocardiogram no significant Q waves are recorded.

Use of Additional Precordial Leads

Additional chest leads are of considerable help in the diagnosis of myocardial infarction. The chief value of the additional precordial leads, the high and low anterior and posterior thoracic leads V_{3R}, V_E, V_{3E}, V_7, V_8, V_R, is that they furnish additional electrical axes through the heart, so that if an electromotive force is more nearly parallel to a particular axis, a more positive or negative deflection will be recorded.

Lead V_{3R} is of considerable help in the diagnosis of right ventricular hypertrophy since it frequently shows the rSR′ pattern when it is not seen in leads V_1 and V_2. It is also occasionally of help in the diagnosis of anterior myocardial infarction, particularly in the anteroseptal region. In such instances a QS complex is present in Leads V_1 and V_2, while an initial r wave is found in Lead V_{3R}.

The high precordial leads are frequently of help in the diagnosis of high anterior and lateral infarctions which are not clearly shown in the usual electrode placements. The findings in these leads are of help chiefly in denoting the presence of abnormalities of T waves and RS-T segments; the presence of QS complexes in these derivations is so often observed as a normal finding that their presence cannot be interpreted as indicative of infarction.

Leads V_7, V_8, and V_B give information relative to potentials directed toward or away from the lateral and posterior portions of the left side of the thorax. The information derived depends upon the portion of the heart involved by an infarct, and these leads may therefore give information about a lateral or posterior myocardial infarct of the left ventricle by recording a significant Q wave.

Additional unipolar Leads V_E (level of ensiform), V_{EO} (midway between *ensiform and the umbilicus) and* V_O *(level of umbilicus) were used by* Lambert.[159] This author states that Lead V_E explores the anterior wall of the left ventricle and septum; Leads V_{EO} and V_O give information relative to the posterior and posterolateral wall of the left ventricle He concluded that Lead V_E showed direct infarction patterns in nearly all anterior, anteroseptal and posteroseptal infarcts and that Leads V_{EO} and V_O usually *show direct patterns of infarction in plain posterior infarcts and in infarcts* which are or become posterolateral. It must be remembered, however, that these additional precordial leads are simply additional axes which may be used to record the electromotive force.

Lower Placement of Precordial Leads: If one takes roentgenograms of the heart in order to determine the relative position of the chest electrode with relationship to the portion of the heart directly beneath it, one frequently finds, especially in ptotic hearts and occasionally in transverse hearts, that Leads V_3, V_4, and V_5 are situated considerably above the main mass of the left ventricle. As a result, they do not record the cardiac potentials as faithfully as they might do somewhat lower on the chest. For example, QS complexes may be obtained where rS complexes should be observed and T wave changes may not appear unless lower leads are taken. If precordial leads are taken an intercostal space lower than they usually are, in addition to those routinely taken, added information may be obtained.

Effect of Posture: Occasionally, in doubtful cases of infarction, the recording of precordial leads in deep inspiration may give added information. Since the anatomic position of the heart changes, certain questionable findings may be obliterated. Similar additional findings are obtained when the tracings are taken in the left lateral position.

Esophageal Leads

Esophageal leads have the added advantage that the exploring electrode is relatively close to the heart and that localized potential abnormalities are exaggerated, since the size of the deflection obtained is inversely proportional to the square of the distance of the exploring electrode from the source of the electromotive force. Thus esophageal leads are valuable in

determining the atrial mechanism in cardiac arrhythmias, since the atrial deflections are greater in amplitude and can be more easily distinguished. Since the esophagus is also anatomically closely related to the posterior wall of the left ventricle, these leads are helpful in the diagnosis of posterior myocardial infarction. This is of special importance in the infarcts which are small and well localized, since no abnormalities may be recorded in limb or precordial leads.

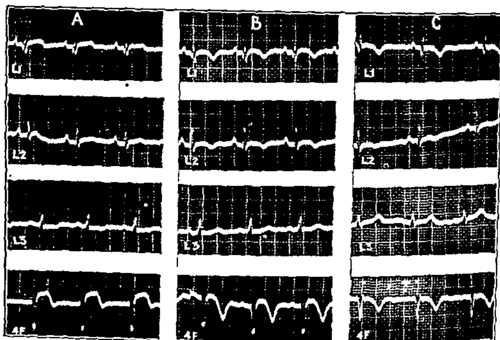


FIGURE 54. Anter[illegible]

[illegible] Note the presence of a small Q wave in Lead I. T_1 is still inverted, but is no longer as characteristically cove-shaped as in *B*. T_2 is inverted still, but not as much as in *B*. Lead IV_F still shows the absence of *R* waves. The RS-T deviations have entirely disappeared. The T waves are inverted but not as deeply as in *B*.

Electrocardiographic Patterns

Anterior Myocardial Infarction: Occlusion of the anterior descending branch of the left coronary artery results in infarction involving the anterior and apical portion of the left ventricle and the lower left contiguous portion of the interventricular septum. An electrocardiographic pattern is produced which is usually fairly characteristic. However, deviation from the typical patterns are frequent.

Acute Stage (Stage of RS-T Deviation): The acute stage is characterized by the presence of RS-T deviation which presents a characteristic pattern (Figs. 49, 50 *B*). This is represented by the T_1 type of RS-T devia-

tion (if a Q wave is present in Lead I, it is called the Q_1T_1 type). With a left axis deviation the RS-T segment is elevated in Lead I and depressed in Lead III; the RS-T segment in Lead II depends upon the algebraic summation of T_1 and T_3. In the presence of a bicardiogram, the RS-T segment is elevated in Leads I and II; $RS\text{-}T_3$ is usually unaffected. The precordial leads show an absence of the initial upward deflection in CR_2, CR_3, CR_4, and often CR_5 with elevation of the RS-T segment. With sub-

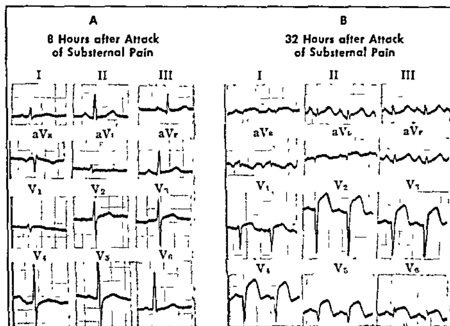


FIGURE 55. Acute anterior infarction *A*. Little abnormal can be seen except for slight flattening of T waves in Leads I, aV_L and the left precordial leads *B*. Shows a QS deflection in Leads I, aV_L, V_2, V_3, V_4, and V_5. The RS-T segments are elevated in these leads, and the T waves are beginning to cove. Note that the T wave is upright in Lead aV_F. This represents a recent myocardial infarction involving the anterior wall of the left ventricle in a vertically placed heart

sidence of the acute stage, the RS-T deviation becomes less marked and finally disappears, first in the limb leads and later in the precordial leads. The RS-T segment deviations do not disappear with equal rapidity in all precordial leads; they may remain in one or more chest positions for many days or weeks after they have disappeared in others.

Subacute Stage (Stage of Rapidly Changing T Waves): With the disappearance of the RS-T deviation, the T wave becomes inverted in Lead I and upright in Lead III with a left axis deviation or inverted in Leads I and II if no axis deviation exists (Fig. 49 *B*). These T waves often have a cove-shaped configuration and the inversion is deep; they change considerably in amplitude and depth of inversion in the course of a few days or a week. The T waves in the precordial leads are inverted, often deeply, frequently accompanied by some RS-T segment elevation, and are often of considerable amplitude[69] (at times 15 to 20 mm.) (Fig 54 *B*, Lead IV_F).

Chronic Stage (Stage of Permanent Change in QRS-T Complex): As healing occurs, the configuration of the T waves becomes stabilized. The deep-coving, rapid change in shape and increased amplitude give way to a T wave of a type that may be permanent for the patient and undergo relatively little change in the course of years. T_1 in the chronic stage is usually inverted. It may, however, become flat or even upright; T_4 mirrors closely the direction of T_1.

The initial upward deflection of the chest lead, which usually disappears in the acute and subacute stage, often does not return even in the healed stage; not infrequently it may return partially (2 to 4 mm.) in some of the precordial leads.

Variations of the Usual Pattern of Anterior Infarction: *The following deviations* from the typical pattern in anterior infarction are observed:

1. The RS-T changes may be absent in the limb leads and only observed in the precordial leads.
2. Following upon an old posterior infarction, the limb leads may be normal for several days after the inception of precordial pain and the changes may later appear gradually.
3. The infarction may be so gradual that RS-T deviations are entirely absent: Only inverted T waves in Lead I are observed in successive electrocardiograms with corresponding inversion of T_4.
4. Following upon an old posterior infarction, the limb leads may show a deep Q_3 and the amplitude of the QRS may be low in all leads, including the chest lead [125]
5. The initial upward deflection in CR_4 may be preserved in the acute stage and the only evidence of coronary occlusion is the characteristic changes of the T wave in limb and precordial leads In this pattern, the T waves are often very tall

Cases of coronary occlusion have been observed presenting electrocardiographic patterns in which the RS-T segment is elevated in Lead I and depressed in Lead III, or cove-shaped inverted T waves appear in Lead I with upright T_3 associated with maintenance of the initial upward deflection in Lead CR_4 throughout the acute, subacute and chronic stages of infarction. Necropsy examination in such cases has revealed the infarction to involve the anterior wall of the left ventricle away from the apex or the anterolateral wall of the left ventricle without involving the apex.

6. Another variation is that the initial upward deflection may be present in the initial tracings and disappear only gradually after a period of several days
7. In the presence of bundle-branch block either preceding or concurrent with the infarction, the pattern is often atypical.

Electrocardiographic Patterns Simulating Acute Anterior Infarction: The following conditions must be differentiated from anterior infarction:

1. A small or absent initial upward deflection in the precordial leads may be due to anterior myocardial infarction or to other conditions mentioned below. The R wave may be absent in the C_2 and C_3 positions in the presence of marked clockwise rotation on the longitudinal axis. The R wave may be small from C_1 to C_2 where there is a shift of the transitional zone to the left, *e. g.*, in left ventricular hypertrophy, left bundle-branch block and occasionally in right ventricular hypertrophy with marked clockwise rotation These electrocardiographic patterns would simulate a healed infarction; any factor that ele-

vates the RS-T segment would result in a resemblance to an acute infarction pattern.

2. Electrocardiographic changes produced by digitalis[30] If the T waves were originally upright, this drug depresses the RS-T interval in all three limb leads in the presence of a bicardiogram; it results in a depression of $RS\text{-}T_1$ and elevation of $RS\text{-}T_3$ with a left axis deviation. In the presence of previously inverted T waves and in myocardial disease, the typical digitalis effects are not

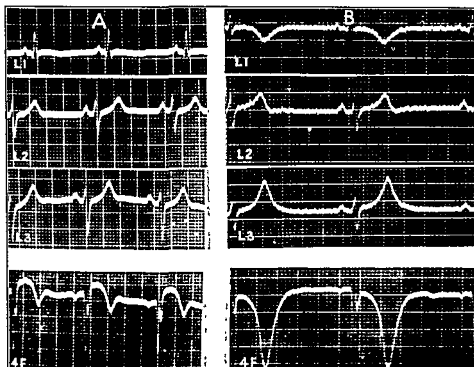


FIGURE 56 Precordial leads during the subacute stage of myocardial infarction. *A* and *B* are from the same case of anterior infarction *A* was taken three days after the onset of severe precordial pain Note the slightly elevated RS-T segments in Lead I with beginning inversion of the T waves The T waves are upright in Leads II and III A left axis deviation is present Lead IV_F shows an absence of R waves with elevated RS-T segments These findings are character-

clearly recognized in the indirect leads However, the RS-T deviations observed are not likely to be confused with the pattern observed in anterior infarction They simulate more closely the deviations observed in posterior infarction Confusion is most apt to result in the precordial leads where digitalis has been given to patients having a small or absent initial upward deflection not due to acute myocardial infarction. With an extremely small (1 to 5 mm.) or absent initial upward deflection, digitalis results in an elevation of the RS-T segment

in Lead CR_4, thus giving a picture resembling an acute anterior infarction Where the initial upward deflection is small or absent, owing to an old anterior infarction, the digitalis RS-T elevation may give a picture resembling an acute anterior infarction. The differential diagnosis is made by the history, by the RS-T deviations in the limb leads (these differ in digitalis and anterior infarction) and its association with short QT intervals (these differ in the two conditions), and by the subsequent course Serial tracings in myocardial disease present an entirely different pattern from that due to digitalis effects

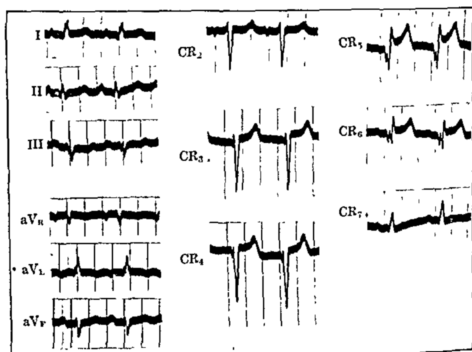


FIGURE 57 Anterolateral infarction. There is a small Q wave in Leads I, aV_L, CR_5, and CR_6 The Q waves are widened and notched in CR_5 and CR_6 The RS-T segment is slightly elevated in Leads I and aV_L and elevated in Leads CR_3, CR_4, CR_5, and CR_6

3. Acute pericarditis. In uncomplicated cases, acute pericarditis can easily be differentiated from acute anterior infarction since in the former the R waves are preserved in the precordial leads, and the RS-T segments are elevated in all precordial and limb leads. Moreover, the findings in the subacute stage of myocardial infarction, cove-shaped T wave and high amplitude T waves, are absent in acute pericarditis.[70]

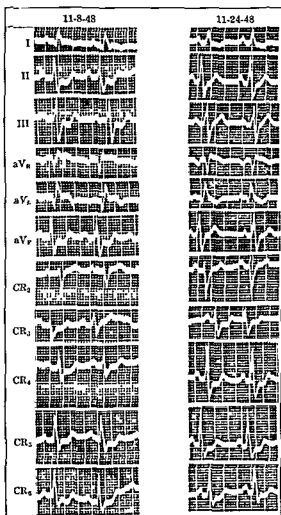
4 Aneurysmal dilatation of the left ventricle (see page 1365).

Subgroups: Anterior myocardial infarction may be divided into the following subgroups: (1) anteroseptal, (2) anterolateral, and (3) high anterolateral.

Anteroseptal Infarction· In this type of infarction the characteristic changes in the QRS complex and RS-T segment are confined usually to the V_2, V_3, and V_4 positions, indicating infarction of that portion of the left ventricle *close to the interventricular septum.* An abnormal QR or QS complex is observed in one or more of these leads. The Q is abnormal when

its amplitude is twenty-five per cent or more of the succeeding R wave and is over 0.03 second in width. The leads V_5 and V_6 and aV_L may show T wave changes. There are no alterations in the QRS.

Anterolateral Infarction: In this type of infarction the diagnostic changes are observed in the QRST, usually in leads from the left side of the precordium V_4, V_5, and V_6, accompanied by similar changes in Lead I and aV_L. The leads from the right side of the precordium are not affected (Fig. 52).



High Anterolateral Infarction: When the infarct is situated in the mid and upper portions of the lateral wall of the left ventricle, the usual precordial leads will give little or no information of its presence. The diagnostic features may be obtained in Lead I, in aV_L and from the left side of the precordium at the level of the second or third interspace. In some instances these leads have been positive for myocardial infarction when other leads have been either negative or equivocal.

Anteroinferior (Diaphragmatic) Infarction: These infarcts can be produced in one of two ways—(1) when the major infarction involves the lower portion of the left ventricle it extends around the apex to involve the lowermost portion of the anterior wall; (2) when the infarct is primarily anterior, owing to occlusion of the anterior descending branch of the left coronary artery, it sometimes extends around the apex to involve the lower or inferior portion of the posterior wall.

Q waves and RS-T segment elevations in the bipolar and unipolar limb leads are found similar to those observed in inferior infarction The precordial leads show QS patterns in Leads V_1 and V_2 and perhaps in V_3 associated with RS-T segment elevation in these leads.

Posterior Myocardial Infarction: Posterior myocardial infarction varies considerably in degree and location of the myocardial damage. Two chief types are observed depending upon (1) whether the occlusion involves the right coronary artery near the orifice, in which case the posterior or posterolateral wall of the left ventricle is infarcted; or (2) if the posterior descending branch alone is occluded, in which case the infarct is smaller since the posterior portion of the interventricular septum and contiguous portion of the left ventricular wall is involved. In addition, varying degrees of subendocardial and intramural infarction are observed. In addition to these factors, the electrocardiographic pattern will vary with the position of the heart.

The diagnostic changes are observed chiefly in Leads II, III, aV_F, and in the esophageal leads at the ventricular level. The precordial leads usually show downward displacement of the RS-T segments in the acute stage, occasionally abnormally tall, upright T waves in the subacute stage. These return to normal T waves in the healed stage (Fig. 55). Occasionally the RS-T and T wave changes are observed more clearly and at an earlier period in the CF leads than in the CR or V leads.

The determination of the electrical position of the heart is essential for the interpretation of the findings in Lead aV_F. In horizontal or semihorizontal hearts, the right surface of the septum transmits its potentials to the left leg and the ventricular complex normally consists of a small R and deep S wave. In such hearts, posterior infarction without involvement of the septum has no effect on this initial (septal) R wave and Lead aV_F may therefore fail to show any signs of the infarct. If the septum is involved, however, a QRS, QR, or a QS pattern may be seen. If a QS pattern is found, it must be differentiated from the QS complex which may occur as a normal variant in horizontal hearts.

In intermediate, semivertical, or vertical positions of the heart, the potential variations of the left surface of the septum and the epicardial sur-

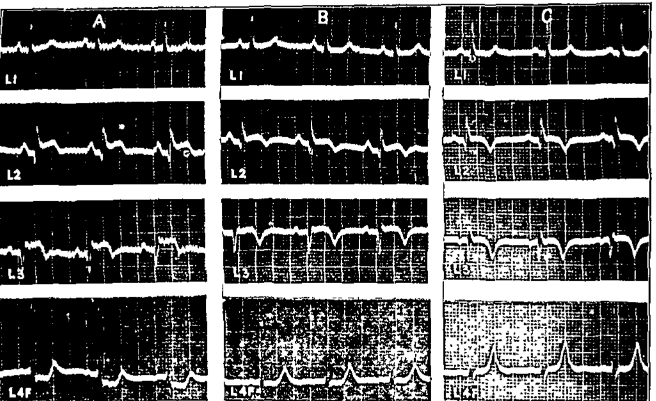


FIGURE 59 Posterior myocardial infarction *A* was taken twenty-four hours after the onset of acute precordial pain Note slight RS-T depression in Lead I, RS-T elevation in Leads II and III and a deep Q wave in Leads II and III IV_F shows a maintenance of the R wave with RS-T depression These findings are characteristic of the acute stage of posterior myocardial infarction Note that the indirect leads give somewhat more information than the precordial lead. *B* was taken five days after *A* Note slight RS-T depression in Lead I, slight RS-T elevation in Lead II, not as marked as in *A* The Q waves are not as deep Lead III now shows deeply inverted T waves but only slight RS-T elevation In IV_F the RS-T depression has entirely disappeared These findings are fairly characteristic of the subacute stage of posterior myocardial infarction C was taken two weeks after *B* Note absence of marked RS-T depression in Lead I, T_2 and T_3 are now inverted The T waves are still inverted in Leads II and III and Q waves are still present but RS-T elevations in Leads II and III are slight IV_F shows no change except that the amplitude of the T wave is slightly higher than in *B* These findings are typical of the subchronic stage of posterior myocardial infarction During the chronic stage, the Q wave in Leads II and III may entirely disappear and T_2 may become upright

face of the free posterior wall of the left ventricle have the predominant effect on aV_F. A QR pattern may therefore appear normally in such hearts. The abnormal QR pattern due to posterior infarction is differentiated on the basis of the following criteria: (1) The Q wave should be over twenty-five per cent of the amplitude of the succeeding R wave; (2) the Q wave should measure 0.04 or more in width; and (3) the abnormal Q wave is frequently slurred.

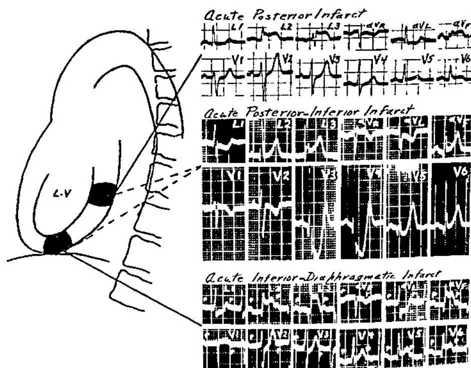


FIGURE 60 Sites of posterior infarction Diagrammatic representation of acute posterior, posteroinferior, and inferior (diaphragmatic) myocardial infarct *A*, Acute posterior infarct (high basal) Note the RS-T segment elevation in leads II, III, aV_F, and V_6, and the tall, upright symmetrical T waves in Leads V_1 to V_4 *B*, Acute posteroinferior infarct Note the RS-T segment elevation in Leads III, [illegible] pression in V_3, V_4, and V_5 which [illegible] *C*, Acute inferior diaphragmatic [illegible] ads II, III, aV_F, V_5, and V_6 with [illegible] V_2, and V_3 The T waves in the [illegible] gree atrioventricular heart block

The typical pattern observed in such cases is as follows:

Acute Stage (Stage of RS-T Deviation): The RS-T segment is depressed in Lead I and elevated in Leads II and III, or in Lead III alone, in the presence of a left axis deviation (Fig. 54 *A*). With a bicardiogram, the RS-T segment is elevated in Leads II and III. The RS-T segment of Lead I is unaffected. A Q wave is often observed in Lead III or Leads II and III. This is often referred to as the T_3, or Q_3T_3 type of QRST change. The precordial Lead IV_F shows a depression of the RS-T segment without change in the initial upward deflection. A significant Q wave may be observed in aV_F.

Subacute Stage (Stage of Rapidly Changing T Waves): With the disappearance of the RS-T deviation, T_1 tends to become upright, T_2 and T_3 inverted; these are often cove-shaped (Fig. 54 *B*). T_3 and the T wave of the precordial leads often show marked increase in amplitude. The depth of the T wave inversion and increased amplitude tends to diminish as healing progresses.

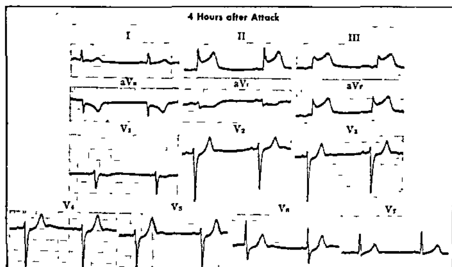


FIGURE 61. Acute stage of posterior infarction The RS-T segments are markedly elevated in Leads II, III, and aV_F They are depressed in all of the remaining leads A small Q wave can be seen in Leads II, III, and aV_F This tracing was taken four hours after a severe attack of substernal pain and represents occurrence of injury with incomplete depolarization involving the posterior wall of the left ventricle

Chronic Stage (Stages of Permanent Change in QRST Complexes): In the chronic stage, the T_2 and T_3 often remain inverted or T_2 may return to an upright configuration. Q_2 and Q_3, if present in the acute and subacute stage, become smaller. Frequently Q_3 persists permanently but it may disappear entirely. T_4 returns to normal. In the healed stage of a posterior infarction there is often little and may be no electrocardiographic evidence of a previous coronary accident, except for the presence of a Q wave in Leads II and III, Leads III, aV_F and in the esophageal lead taken at the ventricular level.

Sites of Posterior Infarction: In the past the diagnosis of posterior myocardial infarction was applied to a varied group of electrocardiographic patterns consisting of T wave and RS-T segment deviations in Leads II, III, and aV_F and in the precordial leads. Correlation of electrocardiographic findings with necropsy examinations has been of help in dividing the infarcts of the posterior wall into the following subgroups:

High Posterior (Posterobasal) Infarction. The site of infarction is confined to the upper posterior portion of the left ventricle, which is usually supplied by the right coronary artery and occasionally by the circum-

flex branch of the left. The RS-T segments are depressed in Lead I and elevated in Leads III and aV_F. Lead V_1 shows tall, broad (0.04 second or over) R waves, while the T waves in V_2 and V_3 are tall and symmetrical and may be associated with RS-T segment depression.

Posteroseptal Infarction: The infarction is usually due to occlusion of the circumflex branch of the right coronary artery, but more often occurs

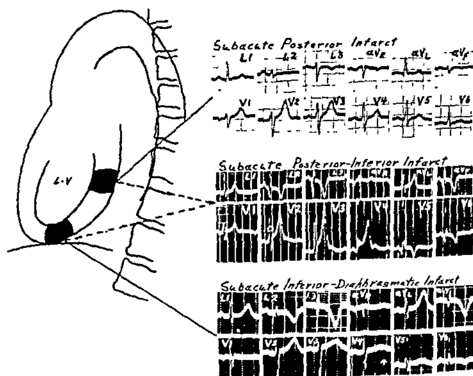


FIGURE 62 Sites of posterior infarction *A*, Subacute posterior infarct (high basal). The T waves are inverted in 3 and aV_F. The significant findings are the tall, wide R waves in V_1, V_2, V_3, and V_4 and the tall, upright symmetrical T waves in the same leads Note that there has not been a significant Q wave, *i. e.*, wide or of great amplitude, in either the acute or the subacute stage *B*, Subacute posteroinferior infarct Note the deep Q wave in 2, 3, and aV_F with inverted, cove-shaped T waves Note the wide R waves in V_1, V_2, V_3, and V_4 followed by tall, upright symmetrical T waves *C*, Subacute inferior-diaphragmatic infarct. Note the Q wave in 2, 3, and V_F with inverted, symmetrical cove-shaped T waves in these leads With the exception of some T wave inversion in V_6, the precordial leads are not remarkable

where the circumflex branch turns at a right angle to become the posterior descending branch. The infarction extends through most of the posterior wall and interventricular septum. The bipolar and unipolar limb and precordial leads show changes similar to those found in posterobasal infarction; in addition, varying degrees of atrioventricular heart block and intraventricular conduction defects may be present. There may also be a Q2, Q_3, and QaV_F. Tall R waves may be present in V_1.

Inferior Infarction (Diaphragmatic): The infarcted area involves the lower posterior portion of the left ventricle, extending to and including the apex. These infarcts are usually in contact with the diaphragm. Significant

Q waves with RS-T segment elevations are found in Leads II, III and aV_F. The precordial leads may be normal.

High Posteroinferior Myocardial Infarction: The precordial leads show wide, tall R waves in V_1, V_2, and V_3 with tall, upright symmetrical T waves, with or without RS-T segment depression. The limb leads show significant Q waves in Leads II, III, and aV_F with cove-shaped, inverted T waves in these leads.

Variations of the Usual Patterns in Posterior Infarction: The following deviations from the usual pattern of posterior infarction are observed:

1. Where the occlusion develops gradually, the RS-T deviations may not develop until two or three days after the inception of precordial pain. They may be entirely absent and only inverted T waves may be observed. In the slowly developing occlusion, RS-T deviations may be slight or absent in the precordial leads.

2. Where there has been a previous old anterior infarction, acute infarction of the posterior wall is characterized by the typical changes enumerated above. In addition, T_1 may be inverted and there is frequently an absence of the initial upward deflection with some depression of the RS-T segment, these additional findings being a result of the old anterior infarct.

3. Posterior infarction, even when it develops suddenly, not infrequently fails to produce RS-T deviations in the precordial leads, although manifesting characteristic changes in the indirect leads. These may at times be elicited by shifting the precordial electrode to different portions of the precordium.

Electrocardiographic Patterns Simulating Acute Posterior Infarction: The electrocardiographic changes in posterior infarction are to be differentiated particularly from digitalis effects In the presence of a bicardiogram, the differentiation is usually not difficult, since digitalis usually produces a depression of the RS-T intervals in all three indirect leads. When digitalis produces T waves that are of the myocardial type (*e. g.*, with upward convex RS-T intervals), the differentiation is more difficult. Even so, there are differences which make the differentiation possible. Posterior infarction causes an elevation of T_2 and T_3 which is not produced by digitalis in a bicardiogram. If no elevation is present, the T waves are usually more deeply inverted and coved in occlusion than they are with digitalis. The presence of a conspicuous Q wave in Lead III is frequently observed and is characteristic of an occlusion; this change is not produced by digitalis.

With left axis deviation, the RS-T deviation in Leads I and III produced by digitalis may be similar to those of posterior infarction. However, digitalis frequently shortens the QT interval and presents a type of RS-T deviation (upward concave rather than convex) which is frequently typical.

The precordial rather than the conventional leads often furnish the best evidence for differentiating between occlusion and the effects of digitalis, in the absence of left axis deviation. The differentiation must be made on such findings as the prominent Q waves in Leads II and III, high ampli-

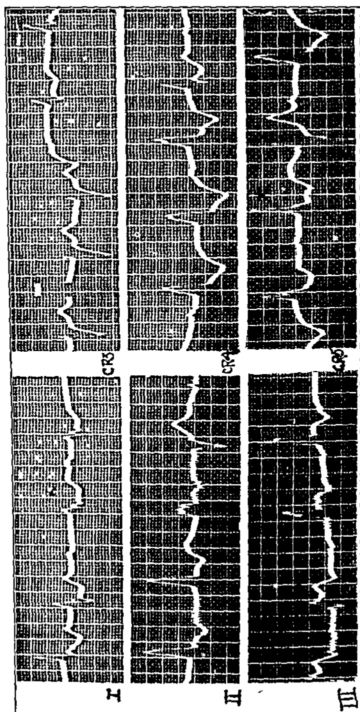


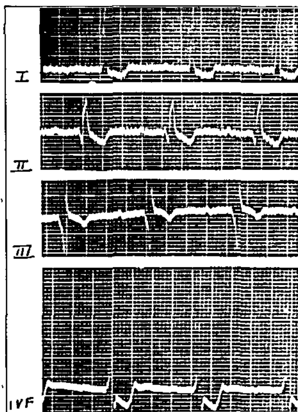
FIGURE 63 Acute posterior myocardial infarction proved by necropsy illustrates difficulty in diagnosis when aberrant complexes resembling those of bundle-branch block appear. The complexes marked X are those which illustrate the characteristic findings, namely, depression of the RS-T segment in Lead I, elevation of RS-T segment in Lead III with Q_3. The complex marked X in CR_5 is the characteristic complex in this patient Note the presence of AV heart block, which is frequently observed in posterior infarction.

tude T waves in the chest leads and the findings in aV_F and esophageal leads.

Posterolateral Infarction: In posterolateral infarction, the infarct occurs in the posterior wall and extends to the lateral wall of the left ventricle. In this type of infarction, in addition to the evidence of posterior infarction as noted above, typical changes are observed in positions V_5

and V_6, which consist of the absence of R waves followed by elevated RS-T segments. The T waves are usually inverted in Lead I.

Significance of the Q_3 and Q aV_F Pattern: A Q wave in Lead III may be found in the electrocardiogram of a normal person with a transverse heart such as occurs in the squat, hypersthenic, obese patient, and during pregnancy, but may also be found in the electrocardiogram of individuals



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with an acute or old posterior myocardial infarction, and with acute pulmonary embolism or acute right heart strain. Pardee[137] and Katz[126] had set up certain criteria to differentiate the two Katz's criteria are as follows: A Q wave is significant of an old posterior infarction if the Q wave is deep and a Q wave is present in Lead II. In an acute posterior infarction, there are also RS-T segment deviations. Pardee's criterion for a significant Q wave in Lead III is that the Q wave be greater than twenty-five per cent of the succeeding R wave in Lead III. Goldberger[138] attempted to show that the unipolar limb leads were of great help in determining whether a Q_3 was significant. He reported that a Q wave in Lead aV_F which had a

duration of 0.04 second and an amplitude of sixty per cent of that of the succeeding R wave or forty per cent of that of the entire QRS complex was diagnostic of posterior infarction.

More recently Gordon Myers and associates[139] have reviewed Pardee and Goldberger's criteria in examination of 110 autopsied cases of posterior myocardial infarction. They showed that the electrical position of the



FIGURE 65. Infarct in a Control tracing within normal limits Clinical in (1/8/54) shows tall, upright symmetrical T w V_5; equivocal electrocardiographic evidence of an acute process in the myocardium. The T wave changes in the standard 12-lead tracing (1/30/54) are now within normal limits, however, the esophageal leads at the 45- and 50-cm level, particularly in expiration, show a definite RS-T segment elevation; note the reciprocal RS-T segment depression in E 35 and E 40.

heart is very important in determining whether a Q wave in the standard limb Leads II and III is diagnostic of posterior myocardial infarction By determining the electrical position of the heart, the interpretation of the findings in Lead aV_F could be made. The direction of the initial phase of the QRS complex was dependent upon the surface of the septum that faced downward, whereas the potential variation of the left leg throughout the remainder of the cycle was governed principally by those of the epicardial surface that rested upon the diaphragm. When the right side of the interventricular septum is directed away from the left leg, a Q wave is inscribed; and when this portion of the septum is directed toward the left leg, the activation is toward the left leg and an R wave is inscribed. In the former, aV_F will be of no help in diagnosing posterior infarction; if a Q wave is present it must be differentiated from the normal by the criteria mentioned above. The esophageal lead taken at the ventricular level may be of help

A significant Q_3, therefore, should always be an incentive to take further electrocardiograms, including unipolar limb leads, to obtain further evidence of its significance. An additional aid, especially where it is clinically permissible, would be to take esophageal leads at various ventricular levels. Such leads may disclose evidence of posterior infarction where it may be absent or equivocal in other leads.

Infarction of the Lateral Wall of the Left Ventricle: The following electrocardiographic patterns may be observed in the presence of lateral

infarction: (1) A depression of the RS-T segment in Leads I and II, or an inverted T wave in Lead I and a depression of the RS-T segments in CR_4, CR_5, and CR_6. This pattern was described by Wood, Wolferth and Bellet.[74] It may be confused with the electrocardiographic findings in



FIGURE 66 Posterolateral infarction Note presence of small Q wave in Lead II and Q wave in Lead III Findings of infarction are most pronounced in CR_4, and CR_6, located on the lateral wall of the left ventricle, where in addition to T wave inversion, depression of the RS T segments is also observed

posterior infarction, pulmonary embolism, digitalis effects and hypertension. This pattern is usually observed in the presence of infarction of the mid or lower portion of the lateral wall of the left ventricle. (2) Abnormal Q waves in V_5, V_6, and/or aV_L. These may or may not be accompanied by elevation of the RS-T segments. (3) In high lateral infarction, which in-

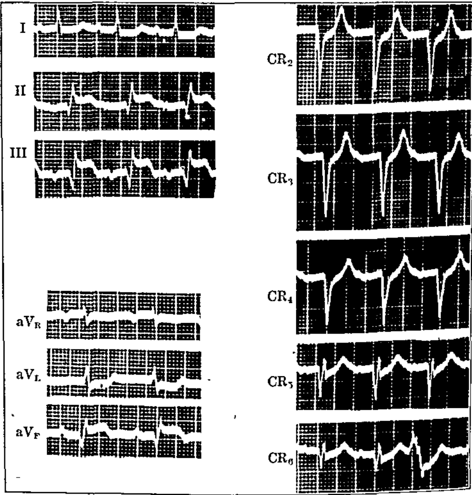


FIGURE 67 Anteroposterior infarction. There is a Q wave in Leads II, III, and aV_F with RS-T segment elevation in these leads The RS-T segments are depressed in Leads I, aV_L, and the precordial leads In addition, the precordial leads show absence of R waves. This tracing represents a healed anterior infarction and a recent posterior infarction.

volves the basal half of the lateral wall, there may be observed an abnormal QR pattern in aV_L, which in some cases may be diagnostic, in others suspicious, of lateral infarction. Lead I frequently fails to show an initial Q wave in these cases Leads in the left axilla may show a QR complex and elevation of the RS-T segment. (4) Myers and associates[140] have recently observed five cases in which the presence of lateral infarction was indicated by QRST abnormalities in one or more of the first four precordial

leads. This was actually suggestive of anteroseptal infarction and was the result of transmission of the potential variations of the infarcted lateral wall to the precordium by marked counterclockwise rotation in three of these cases. (5) We have recently observed two instances of extensive lateral infarction which showed elevation of the RS-T segments in Leads I, CR_4 and CR_5, with slight elevation in CR_6.

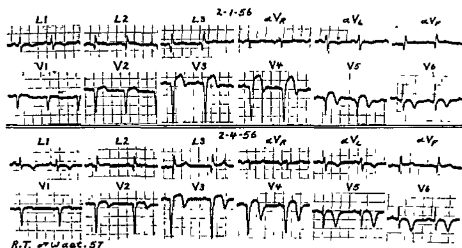


FIGURE 68 Sequential myocardial infarction-healed inferior (diaphragmatic)-acute anterior myocardial infarction R T white male, age fifty-seven years Note the significant Q
of an acute inferior (c
Onset of substernal p
2-1-56. Note the QS d
in Leads V_3, V_4, and V_5 and terminal inversion of the T waves in these leads Three days later the T waves show marked inversion and only slight ST segment elevation The absence of Q waves in Leads 1 and aV_1 suggests that the myocardial infarct involved principally the interventricular septum and that these tracings represent a trans-septal infarct

In addition to the more or less typical pattern of anterior and posterior infarction, other patterns are observed which are more difficult to diagnose electrocardiographically. In a consecutive series of ninety-eight cases of coronary occlusion studied at the Philadelphia General Hospital, sixty-six cases, or approximately seventy per cent, could be classified under the category of more or less typical varieties of anterior and posterior infarction. The remaining thirty per cent belong to the more atypical forms of myocardial infarction. The causes for the occurrence of the atypical patterns are, of course, not always clear. Some examples of atypical infarctions seem to depend upon such circumstances as previous myocardial disease, previous existence of bundle-branch block, presence of previous infarction, the gradual production of myocardial infarction and involvement of more than one portion of the heart by the infarction, *e. g.*, involvement of the anterolateral and posterolateral regions of the left ventricle.

The gradually developing type of myocardial infarction may show no RS-T segment deviations but simple inverted T waves in Lead I, Leads I and II, II and III, and in various precordial leads These may, but need

not be, cove-shaped. The chief diagnostic feature of these cases is the occurrence in a patient with precordial and substernal pain of a relatively rapidly changing configuration of the T waves. This group shows a high incidence of complete return to normal of the electrocardiogram in the healed stage and probably constitutes the most benign type of myocardial infarction. It is in this group, also, that the diagnosis can be missed if frequent serial tracings are not taken.

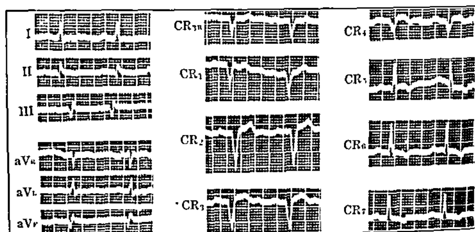


FIGURE 69 Healed anteroposterior infarction A Q wave is present in Leads II, III, and aV_F and in CR_1, CR_2, CR_3, and CR_4 CR_4 may represent the transitional zone This represents infarction of the septum which has extended to involve the epicardial surfaces of the left ventricle, anteriorly and posteriorly.

The occurrence of multiple infarctions is common. These may consist of various combinations of acute and healed infarctions. One may encounter a recent anterior infarction in a patient with an old posterior infarct, or *vice versa*, or a fresh anterior in a heart with an old anterior infarct. Likewise, a fresh posterior infarction may develop upon an old posterior infarction. Various combinations of these with anterolateral and posterolateral types may occur. Simple combinations may be easily diagnosed by the electrocardiogram. Others are difficult to diagnose, unless serial tracings of the previous episodes are available.

Anteroposterior Myocardial Infarction: The anteroposterior type of myocardial infarction is due to occlusion of the anterior descending branch of the left coronary artery. The posterior wall of the left ventricle as well as the anterior wall and apex is involved in those hearts where this branch supplies a considerable portion of the posterior wall of the left ventricle near the apex and where the blood supply to this region by other arteries is inadequate. The latter results when the posterior descending branch of the right coronary artery is small or it may be a result of a previous posterior occlusion.

This type of infarction usually involves the apical one-third of the anterior wall of the anteroseptal portion and the lower one-third of the posterior wall. The lower portion of the interventricular septum is involved, ex-

tending from the anterior to the posterior portion. The infarct may be acute in both the anterior and posterior portions; it may be acute in one and healed in the other; or healed in both (Figs. 67, 69).

The electrocardiographic pattern presents characteristics of acute anterior as well as posterior infarction.[70] In the acute infarct, the RS-T segment is elevated in all three limb leads, greatest in Lead II; a Q wave is

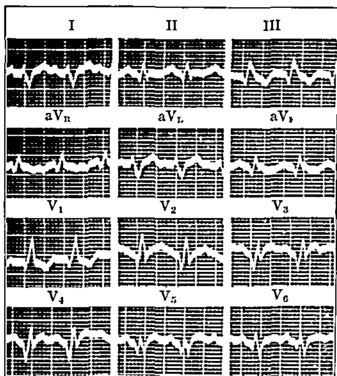


FIGURE 70 Right bundle-branch block with healed septal and extensive anterior and posterior infarction Q waves are present in Leads II, III, aV_F, and all of the precordial leads The QRS complexes are slurred, notched, and widened, measuring 0 12 second Right bundle-branch block is indicated by wide R' in aV_R and tall, wide R in chest leads over the right precordium and deep S waves in the left precordial leads The initial downward deflection in the right precordium suggests a septal infarction The Q waves in other precordial leads are indicative of anterior infarction, the deep, wide Q waves in Leads aV_F, II, and III indicating posterior involvement

present in Leads II and III; the initial upward deflection is absent and the RS-T segment is elevated in precordial Leads CR_2, CR_3, CR_4. Evidence of acute posterior involvement is indicated by the elevated RS-T segment in Leads II and III and the Q_2 and Q_3; anterior, by the elevated RS-T segment in Lead I and the absence of the R wave and elevated RS-T segment in the precordial leads.

Myers *et al.*[141] have observed that Lead aV_F has proved very disappointing for the detection of the extension of a large anterior infarction into the apical portion of the posterior wall. This lead was of greater help in

diagnosis when more than the apical one-third of the posterior wall was involved. They have also observed that in certain hearts the acute anteroseptal involvement failed to show RS-T segment deviations apparently the result of neutralization by opposing negative potentials from the posterior wall.

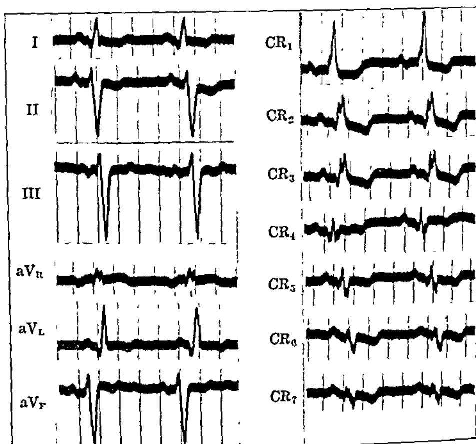


FIGURE 71 Right bundle-branch block with healed septal infarction The QRS complexes are slurred, notched and widened. Note a Q wave in Leads I and aV_L and a small Q wave in all the precordial leads aV_R shows a small initial R wave followed by a small S wave and an R′ and R′′ wave, signifying delay in conduction to the lateral wall of the right ventricle. The precordial leads over the right side of the heart show late, tall R waves preceded by a Q wave Over the left side of the heart, the Q wave persists, but the left ventricle is activated at its normal time, and a broad, prominent S wave is present. This represents myocardial infarction involving the interventricular septum and the anterior wall of the left ventricle with the production of right bundle-branch block. The involvement of the lateral wall of the left ventricle is indicated by the Q waves in Leads I and aV_L and in the left precordial leads

The chief condition to be differentiated from this type of infarction is acute pericarditis. This can usually be done successfully through the fact that in acute pericarditis Q_2 and Q_3 are absent, the initial upward deflection is present in the precordial leads, and the typical coving and tall amplitude T waves of the chest leads are absent in the subacute stages.

Septal Infarction: Septal infarction rarely occurs as an isolated condition. *It is usually combined with anteroseptal or varying degrees of anterior* infarction and in the posterior wall it is associated with posterior myocardial infarction. In massive grades of septal involvement varying degrees of bundle-branch block, both incomplete and complete types, are observed (Figs. 70, 71). Occasionally, the septal involvement may be the most prominent feature observed at necropsy. The diagnostic feature of septal infarction, if right ventricular hypertrophy can be excluded in one group of cases, is the presence of a small Q wave in V_1 and V_2 followed by a small R wave and a deep S wave The same pattern may appear in aV_F in posterior septal infarction in horizontal hearts.

In other instances a monophasic QS complex in V_1 and V_2 plus upward displacement of the RS-T segment and an abnormal Q wave in leads on the left side of the precordium were suggestive of septal infarction The same pattern may be seen in aV_F in horizontally placed hearts.

Myers and associates[142] have observed the following pattern in septal infarction: a QRS interval of 0.12 second or more, a prominent late R wave, delayed intrinsicoid deflection in leads from the right precordium plus a Q wave and/or an abnormally elevated RS-T junction in these leads. This differed from right bundle-branch block because of the abnormal Q waves in right ventricular leads which were produced by the preponderance of negative potentials transmitted from the left ventricular cavity through the infarcted septum. The differentiation of infarcts limited to the septum from those continuing into the anterior wall of the left ventricle depended upon the QRS pattern in the left precordial leads beyond the transitional zone. The electrical position of the heart sometimes makes this interpretation difficult. The recognition of extension of a septal infarct into the posterior wall of the left ventricle was possible from Lead aV_F in the intermediate to vertical cardiac positions but not in transversely placed hearts.

The presence of complete AV heart block resulting from myocardial infarction is usually the result of involvement of the upper posterior portion of the interventricular septum

The diagnosis of septal infarction is difficult in the presence of left bundle-branch block because of the small and occasionally absent R waves on the right side of the precordium Occasionally left bundle-branch block may be the result of extensive septal infarction The presence of a Q wave in Lead I and in the left precordial leads suggests the presence of an infarct of the free wall of the left ventricle or extensive septal infarction.

In the presence of anteroposterior infarction, involvement of the interventricular septum is usually observed.

Myocardial Infarction Complicated by Bundle-Branch Block: The diagnosis of acute infarction in bundle-branch block is often difficult. This is particularly true in the presence of left bundle-branch block In right bundle-branch block, the cavity of the left ventricle is negative at the beginning of the QRS and this negativity is transmitted to the epicardial surface of the infarct or to the cavity of the right ventricle if the septum is involved. In left bundle-branch block, the cavity of the left ventricle is

positive at the beginning of the QRS interval and this positivity is transmitted to the surface of the infarct. If the right side of the septum is also infarcted, the cavity of the left ventricle is negative and this negativity is transmitted to the epicardial surface.[143]

In right bundle-branch block with anterior infarction, there is usually no small R wave in the leads from the right side of the precordium, so that these leads exhibit a prominent Q wave followed by a tall late R deflection owing to delayed activation of the free wall of the right ventricle.

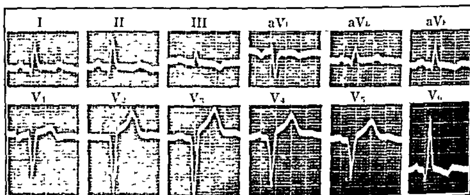


FIGURE 72 Healed anterior myocardial infarction Lead aV_F resembles Lead V_6, while aV_L has no counterpart in the precordial leads so that this heart is in the semivertical position A small R wave is present in Lead V_1 and is absent in all of the remaining precordial leads Note that the T wave is upright in Leads I and II and inverted in Lead III This represents left ventricular hypertrophy in a vertically placed heart where the left ventricular potentials are predominantly referred to the diaphragm Note the absence of the R waves in Leads V_2 to V_5 The transitional zone appears to be broad because there is clockwise rotation in the long axis as well as in the anteroposterior axis

Leads from points farther to the left show large Q waves or QS waves Characteristic changes in the T waves are usually also present. Changes diagnostic of infarction are not as a rule present in the limb leads.

In posterior infarctions plus right bundle-branch block, there are usually large Q waves in Leads II and III and in Lead aV_F. In addition, there are changes in the T waves. The QRS complexes of the leads from the right side of the precordium are like those seen in uncomplicated right bundle-branch block.

In left bundle-branch block with infarction of the free wall of the left ventricle, there is no characteristic modification of the QRS complex in any lead. The cavity of the left ventricle is positive at the beginning of the QRS interval and this positivity is transmitted through the infarcted region to its epicardial surface. The infarct, therefore, cannot produce Q waves or QS deflections. Unipolar leads from parts of the precordium overlying the anterior infarct exhibit QRS complexes which are like those obtained by leads in the left ventricular cavity in left bundle-branch block; these consist of a small or medium-sized R wave followed by an S wave. Infarction of the free wall of the left ventricle plus trans-septal infarction (from left to right) gives rise to QS deflections.

Left Ventricular Aneurysm: Ventricular aneurysm occurs in the apex *on the lateral wall and on the posterior wall of the left ventricle. It* is most frequent, however, on the anterolateral wall of the left ventricle, and is practically always the result of myocardial infarction. The following electrocardiographic signs are suggestive of this type of aneurysm[144]: (1) low amplitude QRS with a Q wave in Lead I; (2) frequently deep S waves in Leads II and III; (3) absent initial upward deflections in the

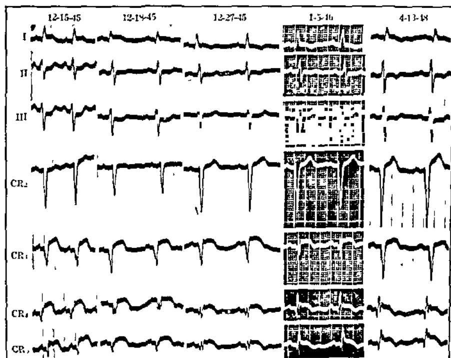


FIGURE 73. Aneurysm of the left ventricle with extensive anterolateral infarction The tracing taken on 12/15/45 shows changes consistent with an acute anterior myocardial infarction Subsequent tracings, including one taken twenty-eight months after the acute episode, show persistent elevation of the RS-T segment in Lead I Note persistent elevation of RS-T segments in precordial leads with absent R waves in CR_2 and CR_1 and Q waves in CR_4 and CR_5

precordial leads from C_2 to C_5 or C_6 position; (4) elevation of the RS-T segments which are present for many months or years without clinical evidence of active myocardial infarction or digitalis effects (Fig. 73). Clinically, these patients usually present evidence of a severe grade of cardiac dysfunction; they are often in a state of chronic congestive failure. The roentgen picture is usually characteristic.

Subendocardial Infarction: The inner zone of the heart muscle is frequently the first portion of the heart involved, and changes are observed in this zone before the epicardial portion is involved. Subendocardial infarction is observed more frequently in the posterior than in the anterior wall Global subendocardial infarction is observed in the presence of syphilitic aortitis with narrowing at the orifices of the coronary arteries

and in prolonged states of coronary insufficiency as, for example, shocklike states. In these, necrosis may be localized in the subendocardial zone.

The electrocardiographic changes in subendocardial infarction consist characteristically of depression of the RS-T segment in Leads I, II, and in the precordial leads, with elevation of the RS-T segments in aVR and in the esophageal leads at the auricular level. A similar pattern may be observed following digitalis medication because this drug results in changes in the heart muscle, particularly marked in the subendocardial zone. In esophageal leads taken at the ventricular level RS-T segment depressions may be observed. In subendocardial infarction where the involvement is slight the T waves may be inverted in the precordial leads without significant RS-T segment deviations. Hellerstein and Katz[132] have shown that, experimentally, in the dog, subendocardial injury of the posterior wall produces an RS-T segment elevation in leads from the anterior portion of the heart.

High Fidelity Electrocardiography

Langner[172] has recorded electrocardiograms utilizing the cathode ray oscilloscope with an amplifier system of high frequency response and an expanded time scale of 330 mm. per second. Such tracings revealed considerable notching, slurring, and beading not seen in the conventional electrocardiogram taken on the same persons. Patients with healed myocardial infarctions and residual Q waves tended to show greater higher frequency detail and bizarre patterns in their cathode ray oscilloscopic records. Several possibilities for future study with this method suggest themselves, the most interesting of which are identification of coronary disease in its incipiency and as an aid in determining the degree of tissue damage or recovery.

Conditions Under Which the Electrocardiogram Fails to Reveal Evidence of Myocardial Infarction

The diagnosis of myocardial infarction may not be indicated by the electrocardiogram under the following circumstances:

1. The electrocardiographic changes may be so evanescent that they may fail to be recorded if too few electrocardiograms are taken. If late in appearance, they may fail to appear in early tracings. For example, the maximum electrocardiographic alterations after anterior infarction at times do not appear until twenty-four to forty-eight hours or even longer after the occlusion. In such instances, tracings taken immediately or soon after the onset of pain would show little change.

2. The presence of RS-T deviations due to digitalis may confuse the diagnosis.

3. In the presence of bundle-branch block, RS-T deviations are often observed independent of infarction; and in left bundle-branch block, the R wave of CR_2 to CR_4 is extremely small (1 to 3 mm.) and is occasionally absent. These factors render the diagnosis of myocardial infarction difficult. However, the complete absence of R wave in Lead CR_4 and the presence of marked RS-T deviations in limb and precordial leads are of help in the diagnosis

4. The presence of low amplitude waves in indirect leads results in correspondingly small RS-T deviations which may not be readily recognizable; the findings in the precordial leads, however, may be helpful and definite.

5 The presence of auricular fibrillation by deforming the RS-T segments may hinder the diagnosis, under these circumstances, the precordial leads are also of help.

6. In the presence of ectopic rhythm with aberrant ventricular complexes (*e. g.*, ventricular tachycardia), the recognition of an acute occlusion is often impossible.

7. When the infarct is small, has as yet not reached the epicardial surface and is located in the septum or some silent area which affects the indirect and the usual precordial leads slightly or not at all, the electrocardiogram may fail to reveal evidence of infarction. In such cases, evidence of relatively rapid changes in the configuration of the T wave without RS-T deviation characteristic of infarction, in the presence of a suggestive history, is to be considered evidence very suggestive of coronary occlusion

Myocardial Infarction Without Coronary Occlusion

Coronary occlusion may be present without myocardial infarction and myocardial infarction may be present without coronary occlusion. The former occurs when the narrowing of the lumen of the coronary arteries occurs so gradually that ample collateral circulation is developed. This is also observed when the patient dies suddenly as the result of a terminal coronary occlusion and insufficient time has elapsed before death for the typical myocardial changes of infarction to occur.

Myocardial infarction without coronary occlusion occurs chiefly in those instances in which coronary insufficiency is maintained for relatively long periods of time. This is apt to occur during shocklike states (surgical, anesthetic and other types), and during the presence of rapid ectopic rhythms, diabetic acidosis, pulmonary embolism and other types of severe heart strain. Under these conditions, the lack of, or diminution of, blood supply to the heart muscle results in diffuse infarction which particularly involves the subendocardial zone of the heart muscle and is not restricted to an isolated portion of the heart supplied by a single coronary artery. On the other hand, in about twenty-five per cent of their cases of young persons with myocardial infarction, Yater and associates[145] and others have found typical myocardial infarction localized to an area of the heart supplied by one coronary artery without thrombotic occlusion of the vessel We now feel that myocardial infarction without thrombosis may produce either of these two pathologic entities.

CORONARY INSUFFICIENCY

By the term "coronary insufficiency" is meant an inadequate amount of coronary blood flow in proportion to the needs of the heart at a particular time. This term is not synonymous with "coronary artery disease," although it is often incorrectly used in this way. A patient may have coronary artery disease, even of an advanced grade, but may not have coronary insufficiency at rest or even upon effort up to a certain point. On the other hand, a patient may have symptoms and signs of severe coronary insufficiency and yet later demonstrate no evidence of coronary artery disease. Coronary insufficiency is not present unless the coronary blood flow is unable to meet the demands of increased cardiac work at a particular time.

Manifestations of Coronary Insufficiency: The diagnosis of coronary insufficiency is not always clear-cut; it may be suspected but can be established only by the presence of certain symptoms and signs, which follow: (1) precordial or substernal oppression which occurs typically upon effort, excitement and occasionally following meals or upon exposure to cold; (2) precordial or substernal pain under the same conditions; (3) pulmonary

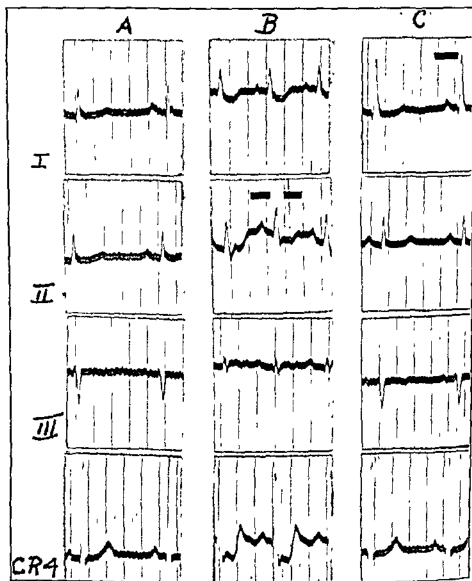


FIGURE 74 Illustrates changes in the RS-T segment of the electrocardiogram following the production of coronary insufficiency induced by exercise in a patient with the anginal syndrome. *A*, Electrocardiogram with patient at rest. Note diminution in amplitude of T waves in Leads I and II, and slight depression in the RS-T segments CR_4 is relatively normal *B*, Following episode of pain after bending ten times Note increase in RS-T segment depressions in Lead I and II and marked RS-T depressions in CR_4 *C*, After resting, the electrocardiogram has returned to its original configuration observed in *A*

edema (usually of acute onset and temporary), occurring in severely damaged hearts, *may be the first sign of coronary insufficiency; (4) electro*-cardiographic changes are important and indeed may be the only objective evidence upon which this diagnosis may be arrived at; they may be slight or absent, but in the classical cases show RS-T segment depression in all leads (both limb and precordial) or occasionally elevation in some precordial leads (they are usually elevated in aV_R). Flattening or transient inversion of T waves may be observed. Inversion of T waves is said to be due to delayed depolarization, RS-T segment depression to incomplete depolarization.[136] Arrhythmias (extrasystoles and paroxysmal tachycardia, especially ventricular tachycardia) may occur. When myocardial infarction has occurred, the various electrocardiographic patterns characteristic of this condition may be observed.

Types of Cononary Insufficiency: Coronary insufficiency may be acute, subacute, or chronic. The acute type is divided into two syndromes· The *first is transient, results from effort or excitement, and disappears when these factors are removed; the other may be due to sudden closure of a* coronary artery and can be fatal. The subacute type is said to exist when the attack lasts from fifteen minutes to several hours. The chronic types of coronary insufficiency refer to those cases in which the coronary blood flow is inadequate to meet the minimum requirements of the patient at rest. This is observed in patients with extensive coronary artery disease, in multiple coronary occlusions and in marked narrowing of the coronary ostia.

Etiology: The syndrome of coronary insufficiency may occur under the following conditions: (1) It usually occurs in patients with disease of the coronary arteries, after coronary artery occlusion and in the presence of narrowing of the coronary ostia; (2) in hypertension and aortic stenosis increased cardiac work with relative impairment of coronary blood flow is involved; (3) in hyperthyroidism, the work of the heart is increased; (4) in anemia there is a combination of increased cardiac work (high cardiac output) *plus impaired nutrition, (5) administration of drugs like pitressin* and ergotamine tartrate results in coronary vasoconstriction with resulting coronary insufficiency; (6) in states accompanied by diminished oxygen tension, *e. g.*, carbon monoxide poisoning; (7) in shocklike states.

Relationship between Coronary Insufficiency and Myocardial Infarction: Myocardial infarction is always due to coronary insufficiency, sufficiently severe and prolonged to produce permanent pathologic changes in the myocardium. On the other hand, as has been shown above, coronary insufficiency often occurs without myocardial infarction. Clinically, it is often difficult to tell, however, when coronary insufficiency has been severe and prolonged enough to produce permanent changes. It has been shown experimentally that when a portion of the heart muscle is deprived of its blood supply for fifteen minutes irreversible changes occur. It is quite likely that with prolonged attacks of "coronary insufficiency," some myocardial change has occurred, even though no electrocardiographic alterations are observed.

PULMONARY EMBOLISM

Acute Cor Pulmonale: The electrocardiographic changes in pulmonary embolism closely resemble those of posterior myocardial infarction. The similar clinical picture increases the difficulty in differential diagnosis. The salient electrocardiographic features of pulmonary embolism (acute cor

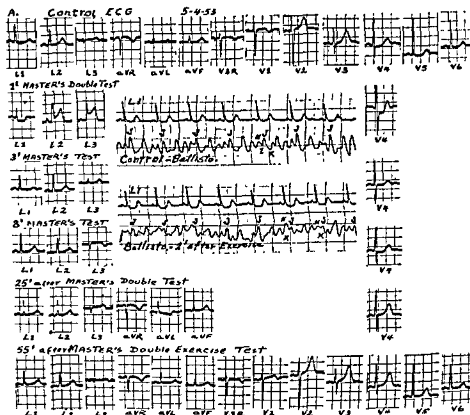


FIGURE 75 The electrocardiogram in acute myocardial ischemia H. T. white male, age fifty-four years, questionable anginal syndrome The control ECG could be considered to be within normal limits; however, note the slight downslope or the horizontal course of the ST segment for 0 12 second or more in all leads except V_1, V_2, and V_3; this finding is often a clue that exercise will give rise to myocardial ischemia and positive findings in the ECG. One minute after exercise note the marked ST segment depression in Leads I and V_4 and ST segment elevation in Leads II and III. Three minutes after exercise the tracing ... after exercise the ... n Lead V_4 ... aV_1; after ... n the complexes can ... I and the marked abnormality of the BCG; note, at X the so-called "early M" pattern frequently seen in patients with coronary artery disease

pulmonale) are: (1) depression of the RS-T segments in Leads I and II with staircase ascent and with an upright T wave; (2) no significant RS-T elevation in Lead III; (3) deep Q_3; (4) deep S wave in Leads I and II; (5) depression of the RS-T segments in the precordial leads and occasionally a right bundle-branch block; (6) prolongation of the QT segment. A

characteristic feature of these changes is their fleeting nature; they frequently disappear in a few days or a week. The electrocardiographic pattern in pulmonary embolism is observed in only about one-third of the cases where it occurs; it is usually seen in the presence of a massive occlusion; and can best be observed in serial tracings. Dack and associates[146] have observed the typical acute cor pulmonale pattern, deep S_1 and Q_3

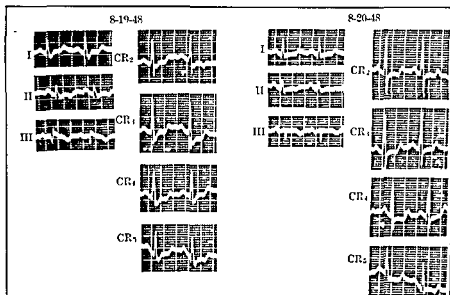


FIGURE 76 Pulmonary embolism with acute right heart strain and transient right bundle-branch block The tracing taken on 8/19/48 shows an S wave in Leads I and II and the precordial leads Lead III shows a Q wave with some elevation of the RS-T segment There is some RS-T segment depression in the precordial leads with a stepladder configuration Tracing taken in twenty-four hours (8/20/48) The width of the QRS complex has returned to normal limits The RS-T segment depression noted in the precordial leads is still present However, the RS-T segment elevation in Lead III has disappeared

and depressed RS-T in Lead I, in only a small portion of their cases of pulmonary embolism. In the majority, the electrocardiographic changes are those characteristic of acute coronary insufficiency; namely, RS-T depression and T wave inversion in one or more leads, and often in all leads

The cause of the electrocardiographic alterations are increased right ventricular strain with coronary insufficiency and myocardial anoxia. Dack and his associates suggest that the important exciting factors of diminished blood flow and myocardial anoxia are systemic shock, right ventricular dilatation, anoxemia and possibly reflex coronary vasoconstriction.

The electrocardiographic pattern in pulmonary embolism should be differentiated from posterior myocardial infarction, lateral infarction and digitalis effects.

Chronic Cor Pulmonale: Chronic cor pulmonale is observed in the presence of mitral stenosis, pulmonary arteriosclerosis, pulmonary emphysema, bronchial asthma, bronchiectasis, pulmonary fibrosis, pneumoconiosis, and

congenital heart disease, particularly of the cyanotic type. All of these states are associated with pulmonary hypertension and hypoxia of the pulmonary circulation. The typical picture of chronic cor pulmonale consists of: (1) a small P wave in Lead I; (2) tall, peaked and unnotched P waves in Leads II and III; (3) low voltage of the limb or limb and chest leads are occasionally observed; and (4) the classical picture in the precordial leads of right ventricular hypertrophy.

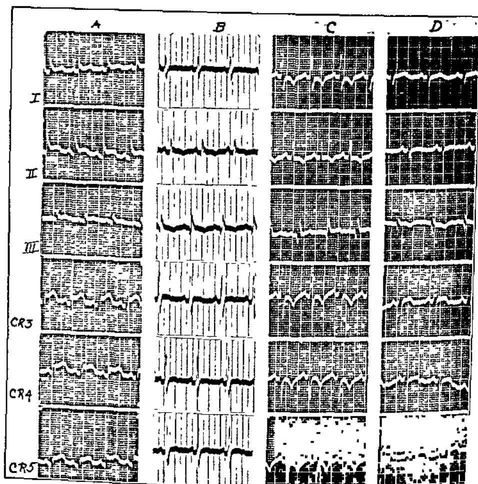


FIGURE 77. Acute pericar[illegible] in all leads (1/24/42). B [illegible] in Lead I, inversion in II, [illegible] acute stage. Note inversion [illegible] stage Note upright T waves in Leads I, II, CR_3, CR_4, and CR_5

ACUTE PERICARDITIS

Acute pericarditis due to various causes (*e. g.*, rheumatism, pneumonia, various septic conditions, intrapericardial rupture of aneurysm and uremia) often produces an electrocardiographic pattern that is quite characteristic.[71] The electrocardiographic findings are explained in most instances by the fact that the inflammation is not limited to the pericardium but spreads to and affects the subepicardial portion of the myocardium. The

muscle injury thus produced and not pericarditis *per se* is, therefore, responsible for the electrocardiographic alterations observed.

The Acute Stage (Stage of RS-T Elevation): The pattern is characterized by an elevation of the RS-T segments in all three leads or at least in Leads I and II, and by elevation of the RS-T segment in the precordial Leads V_2, V_3, V_4, and V_5.

Subacute Stage (Stage of Rapid T Wave Changes): The RS-T elevation gradually disappears and gives way to inverted T waves in Leads I and II or all three limb and precordial leads (Fig. 77 *B*). These T waves show only slight to moderate inversion and do not present the cove-shaped configuration of subacute infarction, nor are very tall T waves observed in this condition. Occasionally the elevated RS-T segment changes to a normal upright T wave without going through the stage of inversion.

Chronic Stage: The inverted T waves may be permanent. In many instances they gradually become flattened and finally return to a normal upright configuration (Fig. 77 *C*). The T wave changes in the precordial leads closely follow those of the limb leads.

All of these stages are not often observed in the same patient. In certain etiologic types, *e. g.*, pneumonia and septic states, the acute and subacute stages are most commonly observed; the return to an upright T wave is seen in those cases where recovery occurs Tuberculous pericarditis usually begins insidiously and is, therefore, not seen until the subacute stage is established The chronic stage can also be studied as a rule, since the disease lasts at times for long periods and occasionally ends in recovery. RS-T deviations in tuberculous pericarditis are rare. In cases of rheumatic pericarditis, one may be able to observe all three stages in the same patient.

The differential diagnosis in this condition is to be made from anteroposterior myocardial infarction, this has already been discussed. The only circumstances in which this differentiation is difficult is when the pericarditis is associated with myocardial infarction

UNSTABLE T WAVES; EFFECT OF POSTURE ON THE ELECTROCARDIOGRAM

Recently, it has been shown that T waves may be not only flat or inverted *in the limb leads of the electrocardiogram but also flat or inverted* in the precordial leads (CR, CF, CL, and V) over the left side of the heart without demonstrable heart disease. This finding is often observed in electrocardiograms of emotionally unstable individuals who may or may not have associated heart disease. Wendkos and Logue[147] and more recently Scherf *et al.*[148] have shown that these T wave changes could be normalized by sympatholytic agents and by change from the upright to the recumbent position The T waves could again be inverted if sympathetic stimulating drugs were used. It was then postulated that these changes, flat or inverted T waves in the electrocardiogram, were in reality due to autonomic nervous system imbalance and not heart disease. Similarly, in some cases vagotonic individuals showed inverted T waves in their electrocardiograms and these changes could be abolished by parasympatholytic agents

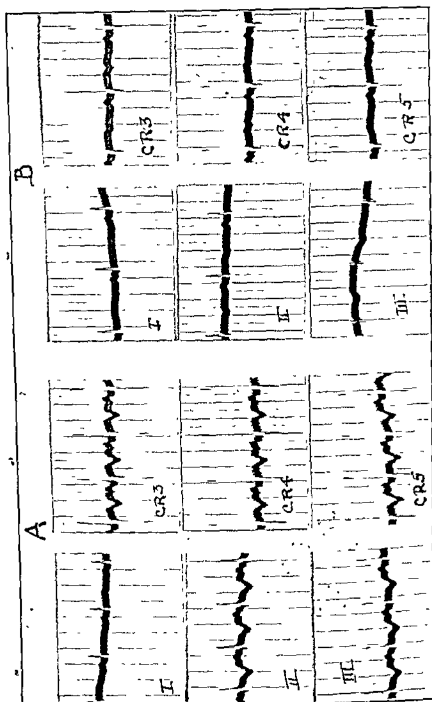


FIGURE 78. Effect of change in posture on the electrocardiogram. *A*, Patient sitting. Note inversion of T waves in Leads II and III, of the limb leads, and in CR_3, CR_4 and CR_5. *B*, Patient supine. Note less deeply inverted T_2 and T_3, and CR_3 and CR_4. In CR_5, the T wave is practically upright

and reinduced with parasympathetic stimulating drugs. This work implied that these drugs, gynergen, atropine, epinephrine, etc., could be used as a diagnostic test to determine whether the electrocardiogram was significant of heart disease. It has been shown, however, that ergotamine tartrate has two effects that are mutually antagonistic. The drug is both a sympatholytic agent and a vasoconstrictor. The net result of its effect will depend upon the predominant action. Scherf and some unpublished work

in our laboratory have shown that T wave abnormalities in coronary artery disease, in recent myocardial infarction and in some cases of hypertension may also be normalized by sympatholytic or parasympatholytic agents. However, use of these drugs, particularly in the presence of coronary disease, is sometimes followed by untoward effects; for example, angina with definite electrocardiographic evidence of coronary insufficiency.

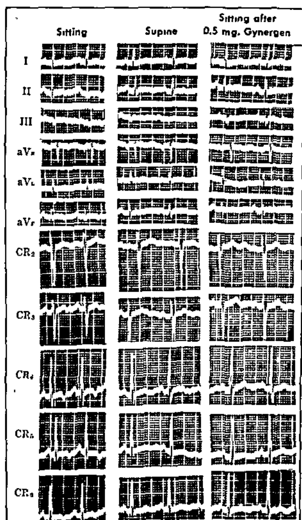


FIGURE 79 Effect of position and sympatholytic drug (gynergen) in patient with unstable T waves The heart is in the intermediate position The T waves are inverted in Leads II and CR_1 to CR_6 when the patient is sitting When the patient is supine or after 0 5 mg of gynergen (ergotamine tartrate) has been given, the T waves become upright

THE ELECTROCARDIOGRAM IN ALTERED METABOLIC STATES

Diabetic Acidosis: In diabetic acidosis, the myocardium may be profoundly affected as a result of many factors, particularly the acidosis, de-

hydration, and profound alteration in electrolytes. The electrocardiographic alterations consist chiefly in changes in the T wave and RS-T segments, although varying types of ectopic rhythms are also occasionally seen. Upon admission in acidosis, the serum potassium may be normal but is frequently high.[149] At this time, the T wave shows the typical changes of hyperpotassemia; it is of increased amplitude, peaked, and the base is narrow After treatment with insulin and glucose, the hyperpotassemia gives way to a hypopotassemia which reaches its maximum usually twelve to twenty-four hours after the institution of therapy. The T-wave and RS-T-segment alterations in hypopotassemia are discussed elsewhere. These changes are reversible and return to normal upon administration of potassium or food by mouth.

Acidosis (Nondiabetic): In cases of nondiabetic acidosis, inversion of T waves in Leads I and II and in the precordial leads has been observed. These returned gradually to normal with improvement in the acidotic state

Alkalosis: Alkalosis produced by voluntary overventilation or by ingestion of sodium bicarbonate may result in a reduction of the amplitude of the T waves accompanied by lengthening of the QT interval.

The alkalosis accompanying vomiting states due to high or low intestinal obstruction is often accompanied by T-wave together with RS-T-segment changes and prolongation of the QT interval; these changes are due chiefly to hypopotassemia.[37,38] These electrocardiographic alterations return to normal with the administration of potassium or when the patient is able to take food by mouth. The alterations in the serum potassium have been shown to vary with the *p*H of the blood. In the presence of alkalosis, the serum potassium tends to drop to subnormal levels.

Hypoglycemia: The effect of hypoglycemia upon the heart depends to a large extent upon the cardiac status. In the presence of already existing myocardial disease, severe additional damage may result. Serious electrocardiographic alterations have been recorded during the hypoglycemic state in such patients, *e. g.*, inversion of T_1, T_2 and in precordial leads, depression of the RS-T segments, ventricular extrasystoles and auricular fibrillation These changes are not always reversible.[75]

In normal hearts, the effect of severe hypoglycemia has been studied during the insulin shock treatment of schizophrenia.[76] In this state, the blood sugar is reduced to 10 to 15 mg. per 100 cc., this level being maintained for several hours. The electrocardiogram in such patients shows changes in about fifty per cent of cases. They are of a less severe grade than in patients with diseased hearts and consist of flattening of the T wave, depression of the RS-T segment, lengthening of the QT interval, sinoauricular heart block, and, rarely, auricular fibrillation (two of forty shock treatments).

Hypocalcemia: Hypocalcemia is observed clinically as a result of removal of the parathyroids, idiopathic hypoparathyroidism, alkalosis accompanying vomiting states, and in uremia. When the level of the serum calcium drops to a figure below 7 mg. per 100 cc., an increase in the length of the QT interval occurs. With low calcium levels, the QT interval is pro-

longed sometimes to almost twice its normal value and the T waves are occasionally inverted. The degree of QT-interval prolongation parallels closely the lowering in the serum calcium, and the prolongation disappears as the serum calcium returns to normal.[91] The lengthened QT intervals may be transiently brought back to normal by the intravenous administration of calcium. The prolonged QT interval due to hypocalcemia may, in many but not in all instances, be differentiated from those due to hypopotassemia. In hypocalcemia, the QT-interval prolongation involves the segment from the end of the QRS to the beginning of the T wave; the T wave proper is unchanged In hypopotassemia, the QT-segment prolongation involves the T wave as well as the segment intervening between the QRS and T wave (Fig. 80).

Hypercalcemia: In hypercalcemia, the QT interval is shortened below its normal value; this returns to normal with the return to a normal serum calcium level. Hypercalcemia is observed in hyperparathyroidism and following the administration of calcium.

Hypothyroidism and Myxedema: In severe grades of hypothyroidism and myxedema, the following electrocardiographic changes are observed: (1) low voltage of the ventricular complexes; (2) flattening or inversion of the T waves in limb and chest leads; (3) occasional RS-T-segment depression; (4) sinus bradycardia; and (5) top-normal PR intervals These changes may be explained by alterations in the myocardium itself; the low voltage could be the result of easier dissipation of the heart current through the myxedematous tissue. It has recently been shown that a pericardial effusion may to some degree be the cause of the enlarged cardiac silhouette In such instances, the low voltage may be explained by the combination of these two factors. The electrocardiographic alterations revert to normal as the basal metabolic rate approaches a normal value.

The above changes are not observed in all cases. They are most frequently seen where the basal metabolic rate has been maintained at a low level for long periods.

Hyperthyroidism: Profound changes may occur in the heart with thyrotoxicosis, particularly if the heart has previously been diseased. The electrocardiographic changes in hyperthyroidism are due to the direct effect of the hormone on the myocardium, overactive sympathetic tone and the excessive cardiac work (high cardiac output) with frequently a relatively insufficient coronary blood flow In some instances, true coronary insufficiency may develop. The electrocardiographic changes frequently observed are as follows: (1) a rapid heart rate, which may be due to a sinus tachycardia; (2) paroxysmal auricular tachycardia, (3) paroxysmal auricular fibrillation or flutter; (4) RS-T-segment depressions in the limb and precordial leads, and occasionally inverted T waves in the limb and precordial leads. These electrocardiographic abnormalities usually return to normal when the basal metabolic rate attains a normal range. Failure to return to normal usually indicates the presence of preexisting heart damage, the residual cardiac effects of prolonged hyperthyroidism, or a combination of these two factors.

The Effects of Hyper- and Hypopotassemia on the Electrocardiogram: The alterations in the electrocardiogram associated with a high serum potassium have been described in azotemia, Addison's disease and preceding treatment in diabetic acidosis. These consist of an increased amplitude of the T wave with the narrowing at the base between the two limbs of the

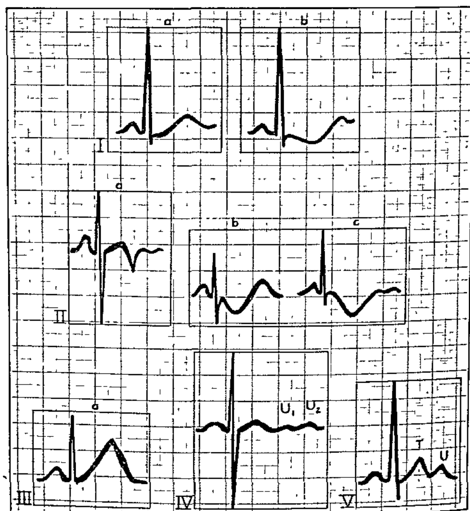


FIGURE 80. Showing varying effects of hypopotassemia on the T wave in RS-T segment (see page 1641). *I*, Note prolonged QT interval and depression of RS-T segment, which is slight in *a* and more marked in *b* *II*, Showing the varying types of T [illegible] of the QT interval. *III*, Sho[illegible] of the QT interval involving [illegible]e T waves with two small U [illegible] prominent U wave.

T wave. These changes return to normal as the level of the serum potassium approaches normal. With an increasing degree of hyperpotassemia the following additional alterations are observed; intra-auricular block and widening of the QRS complexes with a slow idioventricular rhythm. Death from hyperpotassemia with such abnormalities have been reported with serum levels of 10 to 14 mEq./liter.

The electrocardiographic patterns in hypopotassemia are of greater importance because of their frequency. Recognition of these changes is of considerable help in the diagnosis of this state and in following the results of potassium administration. Hypopotassemia is observed in the following conditions: (1) diminished intake of potassium, (2) in patients treated with large doses of desoxycorticosterone, (3) familial periodic paralysis, (4) following treatment of diabetic acidosis, (5) Cushing's syndrome, (6) intestinal obstruction and (7) diarrhea.

There is no single electrocardiographic pattern that may be said to be pathognomonic of hypopotassemia. In a recent study of seventy-nine patients, five electrocardiographic patterns were observed.[37] Sixty-four of the seventy-nine patients (eighty-one per cent) showed two common patterns (patterns 1 and 2). Fifteen patients, or nineteen per cent, made up the remainder of the patterns.

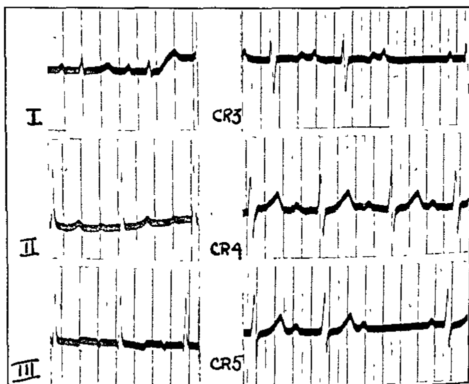
The alterations in the electrocardiogram as a result of hypopotassemia are confined chiefly to the T wave, RS-T segment and an increase in the length of the QT interval. The appearance of a prominent U wave is of additional diagnostic import and will be discussed below. (Fig. 80) Pattern 1 consisted of a depression of the RS-T segment accompanied by lengthening of the QT interval. The degree of RS-T segment depression and lengthening of the QT interval varied in general with the lowering of the serum potassium. The RS-T segment extended from the end of the S wave and then became depressed and joined the peak of the T wave, situated above the isoelectric line With increasing degrees of hypopotassemia, the RS-T depression became more marked; in more severe grades the initial portion resembled an inverted T wave. Pattern 2 consisted of T wave inversion accompanied by QT prolongation and was frequently followed by a U wave. The T wave inversion was of three types: (1) The inverted T wave was situated below the isoelectric line. (2) The inverted T wave manifested a slight elevation of the initial portion of the RS-T segment followed by terminal downward dip. This T wave pattern resembles quite closely that seen in acute pericarditis with subepicardial myocarditis in transient episodes of coronary insufficiency and in certain stages of infarction (T wave in flux). (3) The inverted T waves manifested little or no deviation from the isoelectric line and except for prolongation of the QT segment resembled the inverted T waves seen in various types of myocardial disease

The remaining patterns consisted in prolongation of the QT interval, upright T waves and low amplitude T waves accompanied by a U wave of increased prominence. These patterns consistently could be correlated with a lowering in the serum potassium levels at a level of 2 to 3 mEq./liter. They were immediately reversible following the administration of potassium.

ELECTROCARDIOGRAM IN INFECTIONS AND INTOXICATIONS

While the heart muscle is probably affected to some extent at least by every severe infection, certain infectious diseases have a special predilection for the myocardium; this is particularly true of rheumatic fever and diph-

theria. With severe involvement of the heart muscle, electrocardiographic changes are not uncommon. While syphilis, of course, profoundly affects the heart, the changes that occur in the electrocardiogram are not discussed here since they are generally thought to be the result of chronic effects rather than the acute disease. The changes observed are in many instances reversible and disappear with the termination of the infection.



In other types, particularly rheumatic fever, permanent cardiac damage results. The electrocardiographic changes in the more important infections will be described below.

Rheumatic Fever: In rheumatic fever, certain changes are observed with the acute and active stage of the disease; others are observed with the chronic stage.[78, 79]

In the Acute Stage: It is to be pointed out that not all nor even any of the following changes need necessarily be present. However, when they do exist, they may be of considerable diagnostic and prognostic value

1. *RS-T Elevations:* These may be the result of large areas of focal myocarditis; often apparently, they are due to subepicardial involvement of the myocardium, secondary to acute rheumatic pericarditis.

2. *T Wave Changes:* The T waves may be of low amplitude, diphasic, inverted, or notched, and occasionally they manifest bizarre shapes that are difficult to describe.

3. *QT Interval:* The QT interval is often prolonged.[150]

4. *Conduction Disturbances:* The most frequent and consistent change is prolongation of the AV conduction. This is frequently so transient that it may be present one day and absent the next. Higher grades of AV heart

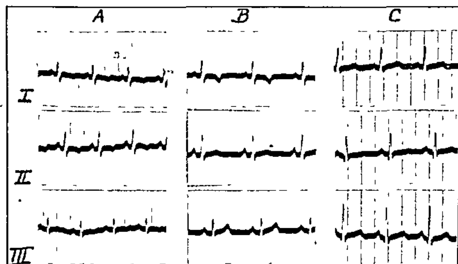


FIGURE 82 Illustrates electrocardiographic changes occurring in acute glomerulonephritis Patient aged twenty-nine *A*, Note inverted T waves in Leads I and II (10/12/43). *B*, Note increase in inversion of T_1 T_2 is now upright (11/8/43) *C* (12/15/43), Tracing has now returned to normal

block, 2:1, 3:1, are infrequent, complete AV heart block is rare. Although AV heart block is an important electrocardiographic evidence of rheumatic activity, this should not be considered pathognomonic for rheumatic fever since it may be observed in other infections.

Bundle-branch block is seen occasionally.

5. *Arrhythmias:* Various arrhythmias may be observed. Extrasystoles are frequent; sinoauricular heart block, auricular fibrillation and flutter are occasionally encountered.

In the Chronic Stage: All of the changes may disappear with subsidence of the acute disease and the electrocardiogram may return entirely to normal; usually, however, some change remains permanently. Where the myocardial damage has been considerable, inversion of the T wave and auricular fibrillation may persist if they originally appeared during the acute stage of the disease, or they may appear as a development in the course of rheumatic heart disease long after the acute process has subsided. Other arrhythmias may also appear. With various valvular lesions, axis deviation may become a permanent change: right axis deviation with mitral stenosis and left axis deviation with aortic valvular disease. The P waves may be notched and their base broadened with severe auricular muscle

damage. Bundle-branch block, right or left, may develop as a result of scar formation in these regions or because of hypertrophy and/or dilatation of the respective ventricles.

Scarlet Fever: Occasionally, scarlet fever produces the same cardiac changes that result from rheumatic fever. When this is the case, the same electrocardiographic changes that develop in rheumatic fever may be seen. In our experience, they are apt to be less severe.

Acute Nephritis: Acute glomerulonephritis, particularly as it occurs in children and young adults, is to be considered not as a local condition involving only the kidney, but rather as a systemic disease in which many organs including the heart may also be involved. The smaller blood vessels throughout many of the organs of the body are the seat of acute changes. Evidence of cardiac involvement may be noted clinically by cardiac enlargement, tachycardia, alteration of heart sounds and even congestive failure The electrocardiogram often presents evidence of severe myocardial damage[82]: T_1 and T_2 may be flattened or inverted; the PR interval may be prolonged, the T waves in the precordial leads are diminished in amplitude, flattened or inverted. On the other hand, electrocardiographic changes may not be marked, and occasionally none may be seen. Changes that are produced may return to normal with diminution of the infection.

Pneumonia: Pneumonia may produce severe cardiac damage; in some instances, death may result from this cause. Evidence of myocardial derangement may sometimes be revealed by serial electrocardiographic tracings.[81] RS-T elevations are usually the result of myocardial involvement due to spread from a pneumonic pericarditis and when present should suggest this condition Flattening of the T waves and depression of the RS-T segment, prolongation of the AV conduction time and sinus bradycardia (rate 40 per minute) are not infrequent. Manifestations of severe myocardial derangement, such as actual inversion of the T wave, the inception of auricular fibrillation and flutter, are much less frequent; when they develop, they indicate a poor prognosis. Since, with the exception of pericarditis, these changes are a result of toxemia, they are usually reversible and disappear with the subsidence of the disease. However, at times these changes along with clinical evidence of myocardial weakness, may persist for some time.

Diphtheria: Diphtheria not infrequently affects the heart muscle. It produces a severe type of interstitial myocarditis and is accompanied by an intense grade of myocardial degeneration.

In fifty per cent of fifteen cases of severe and moderately severe diphtheria, inversion of T waves was observed during the acute illness and in convalescence; these returned to normal after several weeks.[81] Disturbances of intraventricular conduction have also been observed; these have been ascribed to toxic depression of the conduction system. Prolongation of AV conduction occurs not infrequently. Of nineteen cases of complete heart block occurring during the course of acute diphtheria, all terminated fatally.[84]

If the disease is survived, electrocardiographic and clinical evidence of heart disease usually disappears. Occasionally, disturbances in AV conduction persist.

The Electrocardiogram in Cardiovascular Syphilis: There are no characteristic electrocardiographic findings associated with syphilitic heart disease. However, the electrocardiogram is of help in diagnosing or confirming the presence of some of the complications of syphilitic heart disease. The following electrocardiographic patterns are observed: (1) RS-T segment and T-wave changes of the type observed in coronary insufficiency (due to stenosis of the coronary ostia). Occasionally, inverted T waves are observed in the limb and precordial leads of patients with acute syphilis, which may undergo spontaneous changes from day to day. Whether these T waves belong to the "unstable type" or are the result of narrowing of the coronary ostia or other type of cardiac involvement cannot be stated. (2) In aortic insufficiency, the electrocardiographic pattern of left ventricular hypertrophy is usually observed which may eventuate in left bundle-branch block. (3) Auricular fibrillation is rare in the younger age group but is not uncommon in advanced periods of life where it is associated with an atherosclerotic process. (4) Partial AV heart block is observed occasionally, and complete auriculoventricular heart block is rarely observed.

THE ELECTROCARDIOGRAM IN HYPERTENSION, CHRONIC NEPHRITIS AND UREMIA

Hypertension: In hypertension, the electrocardiogram may be normal, but in the more advanced stages, there are usually evidences of abnormalities. In the early stage there may be evidence of left axis deviation which bears no definite relation to the cardiac configuration. As the hypertension progresses and the heart enlarges, evidence of left ventricular hypertrophy appears. These changes are reversible when the blood pressure returns to normal, as for example following a Smithwick operation. The electrocardiogram is important in determining the degree of hypertrophy and gives some idea of the strain the heart has been called upon to bear. In the later stages, left bundle-branch block frequently appears, although in some instances a right bundle-branch block is observed. This is probably due to localized involvement of the right side of the interventricular septum. As the heart strain progresses, these patients frequently develop congestive heart failure which leads in addition to right ventricular hypertrophy. As a result, some cases of hypertension present an electrocardiographic pattern of combined right and left ventricular hypertrophy. Because there is no increase in the myocardial capillaries as the heart hypertrophies, the coronary blood flow remains relatively inadequate to supply the increased muscle mass. Because of these factors, coronary insufficiency results, with the production of RS-T segment deviations in Leads I and II and the precordial leads, particularly marked on the left side of the precordium.

Uremia: In chronic nephritis and uremia, we are usually dealing with a heart which has been subjected to the strain of hypertension and the myocardial changes which accompany this state for a long time. The heart is usually considerably enlarged and often the seat of various grades of myocardial disease. Electrocardiographic characteristics of hypertensive heart disease (left axis deviation and inverted T waves) are therefore usu-

ally seen. With retention of nitrogenous products, additional severe acute degeneration of the myocardium may result (the myocardial degeneration of uremia).[85] With this, the electrocardiogram usually becomes more abnormal. If the T waves were not already inverted, they are apt to become so. If originally upright, they may invert. Arrhythmias (*e. g.*, sinoauricular heart block and nodal rhythm) are occasionally encountered. With the onset of pericarditis, RS-T elevations may be noted in limb and

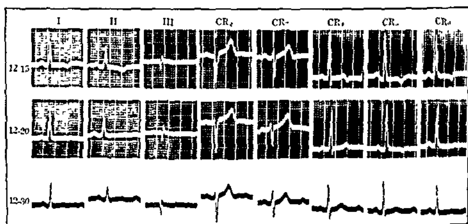


FIGURE 83 Beriberi heart d ... following therapy Note inversion of T waves in ... lowing institution of therapy ... tion There is evidence of im ... flattened in the limb leads and inverted in CR_5 and CR_6 but to a lesser degree than on 12/15/48 On 12/30/48 the T waves are upright in Leads I and II and in the precordial leads

precordial leads. While it is difficult to describe all the variations, it is our experience that serial tracings made during long-standing uremia tend to show a progressive increase in the severity of the electrocardiographic findings.

In some instances, the T wave shows the typical pattern of hyperpotassemia; and in the later stages of potassium intoxication (serum potassium values of 8 to 12 mEq./liter), there are observed periods of sinoauricular block, sinus pauses, and a slow idioventricular rhythm. Death has occurred with such findings and has been attributed to toxic potassium effects because of the high potassium values and their similarity to these changes observed in the experimental animal. In addition, prolongation of the QT interval may be observed due to hypocalcemia.

THE ELECTROCARDIOGRAM IN AVITAMINOSIS

Disturbances of cardiac function may develop as the result of an unbalanced food intake, particularly when there is a deficiency of vitamin B_1. Previously normal as well as diseased hearts may be affected. The cardiovascular manifestations are ascribed partly to involvement of the nervous system and partly also to change in the heart muscle. In severe cases, right and left-sided heart failure may result. The chief electrocardio-

graphic changes observed are simple tachycardia, sinus bradycardia, T-wave changes (flattening and inversion of T_1 and T_2 and in precordial leads), low amplitude of ventricular complexes and lengthening of QT interval. With rest, and a suitable dietary regimen, the evidence of cardiac abnormalities often rapidly disappears.[86,87]

Pellagra is often associated with evidence of cardiovascular abnormalities, dyspnea on effort, palpitation, tachycardia and slight edema. Feil,[88] studying the electrocardiogram in cases of pellagra, noted inversion of T_1 and T_2, elevated and cove-shaped RS-T segments and prolongation of the QT interval.

THE ELECTROCARDIOGRAM IN ANEMIA

Severe anemia results in an inadequate blood supply to the heart muscle, and in addition there is an increase in myocardial work because of the high cardiac output in order to compensate for the anemia. If the anemia lasts for a prolonged period, heart failure supervenes (high-output failure). Changes have been observed in the heart muscle resulting from the anemia, among these are cardiac enlargement due to dilatation and fatty degeneration. The commonest electrocardiographic changes are typical of those observed in acute coronary insufficiency; namely, depression of the RS-T segments in the limb and precordial leads, and inversion of the T waves. Changes of acute coronary insufficiency are not infrequently observed following acute hemorrhage in patients with coronary artery disease. These changes are usually reversible as the blood picture returns to normal

THE ELECTROCARDIOGRAM IN CONGENITAL CARDIAC ANOMALIES

The electrocardiogram in congenital cardiac defects depends upon the type of anomaly. Usually there are observed right or left ventricular hypertrophy and, occasionally, damage to the auricular and ventricular myocardium. The following patterns are observed: (1) The electrocardiogram may be normal; (2) left ventricular hypertrophy is observed, *e. g.*, in congenital aortic stenosis, coarctation of the aorta, tricuspid atresia, and occasionally in patent ductus arteriosus; (3) right ventricular hypertrophy is observed in right to left shunts, *e. g.*, in tetralogy of Fallot, Eisenmenger complex, intra-auricular septal defects and isolated pulmonary stenosis; (4) combined right and left ventricular hypertrophy is seen in conditions where both right and left ventricular strain are present, *e. g.*, in patent ductus arteriosus and isolated interventricular septal defects.

Character of Complexes: The QRS complexes in congenital heart disease are often of markedly increased amplitude.[30]

Bundle-Branch Block: Right bundle-branch block may be observed in interauricular septal defects Bundle-branch block is also occasionally observed in interventricular septal defects where the defect has interrupted the course of one of the main branches of the bundle of His.

Arrhythmias: Various arrhythmias may be observed as a terminal event in congenital heart disease. During the course of the disease, however supraventricular ectopic rhythms, particularly auricular extrasystoles,

auricular flutter and auricular fibrillation, as well as prolongation of the PR interval, may be observed in interauricular septal defects

We have observed instances of the Wolff-Parkinson-White syndrome in cases of tetralogy of Fallot. These patients were subject to attacks of paroxysmal auricular tachycardia. Complete AV heart block has been observed in conjunction with large auricular and ventricular septal defects.

Inverted T Waves: Inverted T waves may be observed as a concomitant of right ventricular hypertrophy on the right side of the precordium and on the left side of the precordium in left ventricular hypertrophy. Inverted T waves may be observed in other leads in association with idiopathic ventricular hypertrophy and in those instances where the coronary arteries arise from the pulmonary artery.

In congenital dextrocardia Lead I is an inverted image of the normal QRST complex. Lead II resembles normal Lead III, and Lead III resembles normal Lead II. To determine the electrocardiographic pattern in precordial leads from C_1 to C_6, instead of recording these from the right parasternal line in the fourth interspace to the left axilla, one starts from the left parasternal line and proceeds to the right axilla, using portions on the right precordium corresponding to those on the left precordium.

THE ELECTROCARDIOGRAM IN PREGNANCY

The primary change in the electrocardiogram in pregnancy is a shift of the electrical axis of the heart to the left. This usually occurs in the last trimester of pregnancy and is due chiefly to a more transverse position of the heart A deep Q wave is often observed in Lead III followed by an inverted T wave The amplitude of the ventricular complexes in the electrocardiogram may also be diminished because of the elevation of the diaphragm and rotation of the heart. These changes are usually transient and disappear after delivery.

Various arrhythmias may be observed in pregnancy, particularly in the presence of previous myocardial damage. These are seen especially in rheumatic and hypertensive hearts with or without evidences of congestive failure. Auricular fibrillation and flutter are occasionally observed. These add considerably to the hazard of pregnancy. Auricular and ventricular extrasystoles are not infrequently observed. Ventricular paroxysmal tachycardia has also been reported during pregnancy.[151]

The electrocardiographic findings of pulmonary embolism have been recorded during pregnancy and the puerperium. Coronary occlusion has also been occasionally reported during pregnancy.[153]

Inversion of the T waves in the limb and precordial leads may accompany the increased strain of pregnancy or may be the result of various cardiac abnormalities or myocarditis accompanying pregnancy. T-wave inversions may also be observed during or following episodes of eclampsia.

THE ELECTROCARDIOGRAM IN SYNCOPAL ATTACKS

Syncopal attacks are not particularly common in heart disease. We have already referred to syncope as an occasional manifestation of very rapid heart rates, particularly auricular flutter with a 1:1 AV ratio. We wish under this heading to refer to two other varieties of syncope in which de-

rangement of the normal cardiac mechanism plays a role. These are: (1) the syncope occurring in Stokes-Adams seizures, and (2) that produced by vagal impulses which originate in the carotid sinus. The former is always seen in severe heart disease, the latter may develop in the presence of entirely normal hearts.

Stokes-Adams Seizures: Stokes-Adams attacks are due to either failure of normal ventricular contraction in the course of complete AV heart block or during the transition from normal sinus rhythm or partial block to complete AV heart block. Periods of asystole, lasting three to nine seconds, are sufficient to produce syncopal attacks alone or accompanied by convulsive seizures. The following mechanisms have been recorded by the electrocardiograph during such attacks: prefibrillatory types of ventricular tachycardia; ventricular fibrillation; ventricular standstill with continuation of auricular beating; and standstill of the whole heart. These may occur singly or in various combinations; all of these may at one time or another be observed in the same patient.

Carotid Sinus Syncope: Carotid sinus syncope may be divided into three types: the cardioinhibitory type, the vasodepressor type, and the cerebral type.

The Cardioinhibitory Type: The cardioinhibitory type is characterized by varying periods of cardiac standstill, the electroencephalogram taken simultaneously shows the characteristic waves of cerebral anoxia These seizures occur spontaneously and may be induced by carotid sinus pressure. The attacks are the result of vagal reflexes which are mediated through the carotid sinus. The afferent fibers are located in the esophagus, in various portions of the gastrointestinal tract, and in the genitourinary and respiratory tracts. They also connect with the eye (oculocardiac reflex).

The syncope results from cerebral anoxia and is produced by a sudden cessation of ventricular beating or a diminution in the number of ventricular contractions which results from vagal influences on the sinoauricular and auriculoventricular nodes. Associated with this is a fall in blood pressure. If the vagal effects are slight and only produce a moderate slowing of the ventricles, the symptoms will be slight. However, the electrocardiogram reveals the exact nature of these effects, which may result in complete suppression of ventricular contractions or in varying grades of partial or complete AV heart block during periods of stimulation.

The Depressor Type: This form is rare by itself; it usually occurs in association with the other two varieties. The afferent impulse is set up as in the vagal type from the carotid sinus while the efferent impulse acts on small blood vessels by way of the aortic depressor nerves. The symptoms result from primary reflex vasodilatation and secondary depression of the blood pressure, entirely unrelated to cardiac slowing and cardiac arrhythmia.

Cerebral Types: The symptoms result from impulses that travel directly to the brain. No significant changes occur in the heart rate or blood pressure during the attack.

The Vasodepressor Type: The vasodepressor type of syncope* is by far the most frequent of all types of syncope encountered. This type of syncope occurs characteristically in the erect position, and the symptoms are quickly relieved by assuming the recumbent position. During the syncopal attack the blood pressure falls to about 80 mm. and the heart rate drops to about 40 to 50 per minute. Asystole of the heart is not necessarily present. Atropine will not be effectual in preventing this type of syncope.

The primary disturbance is related to a failure of the blood-pressure regulating mechanism to function normally in the erect position, with pooling of blood in the lower portion of the body due to loss of muscle, venous and arteriolar tone. The actual loss of consciousness is due to two factors: (1) diminished cardiac output and (2) insufficient systolic pressure to raise the blood from the heart to the brain. The unconsciousness is an expression of acute cerebral anemia. This is shown by the electroencephalogram, which invariably shows high voltage waves, 2 to 4 per second at the point of loss of consciousness, but no change during the premonitory phase.

The precipitating factors are: (1) reflex or psychologic factors, *e. g.*, venipuncture, minor injury, viewing an operation or hearing bad news; and (2) structural cause, *e. g.*, hemorrhage, hot environment, strenuous exercise, acute dehydration and severe infection. This is usually a first-time phenomenon. Repetition of stimulus does not necessarily lead to recurrence.

ARTEFACTS IN THE ELECTROCARDIOGRAM

The recognition of artefacts in the electrocardiogram is of importance particularly to those who have not had wide experience in the interpretation of electrocardiographic tracings. Most artefacts are easily recognized. These differ somewhat in the string and in the amplifier-model instruments. Some of the common artefacts follow: A loose string or indirectly, high resistance may lead to overshooting of the string, resulting in widening of the QRS complexes and deformity of the RS-T segments. Temporary disconnection of the galvanometer produces isoelectric periods which could be interpreted as resulting from cardiac standstill. Movements of the patient or extremity, coughing or spasmodic movement may produce a configuration resembling that of impure flutter or fibrillation. Jarring of the instrument may cause vibrations similar to those seen in coarse auricular fibrillation. Neighboring electrical installations may also induce artefacts which may resemble P waves or peculiar QRS complexes Electric motors may produce electromagnetic disturbances which result in waves which resemble those seen in auricular flutter or auricular fibrillation. Muscle tremors may produce varied artefacts, some of which may resemble fibrillation or flutter waves, whereas others may distort all the complexes so that they cannot be read. When another person is in contact with the electrodes placed on the patient, there will result additional complexes throughout the tracing which are produced by the second indi-

*This type is not to be confused with the depressor type of carotid sinus syncope, which is relatively rare.

vidual. Base-line wandering may be respiratory in origin or it may be due *to loose application of the electrodes. Abrupt base-line changes* may be due to cough, hiccup, twitches or other spasmodic movements of the patient, or to a loose contact in the galvanometer circuit. Improper movement of the film may also produce marked distortions; if the film moves too slowly, a tachycardia will be simulated and if too rapidly, a bradycardia

Improper connection of the lead wires will result in inverted T waves and P waves in Leads I and II and in the precordial leads and present a picture resembling that of serious heart disease. In the precordial leads, two types of artefacts may be encountered. (1) the reversal of the exploring and indifferent electrode results in a QRS deflection opposite to that normally obtained, thus giving a pattern resembling that of an anterior infarction. (2) It is extremely important that the exploring electrodes be properly placed in the various positions on the precordium. For example, if the precordial electrode is moved toward the base of the heart, there results a marked reduction in amplitude of the R waves and a change in configuration of the RS-T segments

When serial tracings are made, the electrocardiogram should always be taken with the patient in the same position Comparison of electrocardiograms taken in the recumbent and sitting positions will show alterations independent of myocardial change, which in turn may result in an incorrect diagnosis.

PROCEDURE IN INTERPRETATION OF ELECTROCARDIOGRAPHIC RECORDS

For beginners in electrocardiographic interpretation it is advisable that a systematic routine be followed in reading a record. By so doing, one will be less likely to make omissions in important parts of the electrocardiogram. The following procedure is one of the many which have been recommended:

1. Look over the record and examine it from the following standpoints (*a*) photography; (*b*) presence of artefacts; and (*c*) manner in which limb and precordial leads have been taken and mounted
2. Note the *auricular and ventricular rate.* Is the rhythm regular or irregular?
3. *P waves*—upright, notched, increased amplitude.
4. *PR interval*—normal, shortened, prolonged, irregularity of PR interval in different cycles.
5. *QRS complex*—notched, widened, slurred, axis deviation.
6. *T waves*—upright, flat, diphasic, inverted T.
7. *RS-T segments*—elevated, depressed, reciprocal relation of Lead I and Lead III, precordial lead, aV_R, aV_L, and aV_F.
8. *Precordial Leads.* (*a*) Note (1) normality or abnormality of leads on right side of precordium (V_1 and V_2); (2) transitional zone (V_3); (3) left side of precordium (V_5, V_6).

(b) Note character of QRS complexes (widening, notching), intrinsicoid deflection (delay on right or left side of precordium), site of transitional zone, amplitude of R waves, absence of R waves.

TABLE II

Table for Calculation of Heart Rate

(The Following Table Can Be Used if the Rhythm Is Regular)

Length of cycle in 1/25 sec.	*Rate per min.*	*Length of cycle in 1/25 sec.*	*Rate per min.*	*Length of cycle in 1/25 sec*	*Rate per min*
5	300 0				
5½	272.7	20½	73.2	35½	42 2
6	250 0	21	71.5	36	41.7
6½	230 8	21½	69 8	36½	41 4
7	214 3	22	68.2	37	40 6
7½	200 0	22½	66 7	37½	40 0
8	187.5	23	55 2	38	39.5
8½	176 5	23½	63 8	38½	39 0
9	166 7	24	62.5	39	38 5
9½	157.9	24½	61.2	39½	38 8
10	150 0	25	60 0	40	37.5
10½	142.9	25½	58 8	40½	37 0
11	136.4	26	57.7	41	36 6
11½	130 4	26½	56.6	41½	36 1
12	125.0	27	55.6	42	35.7
12½	120 0	27½	54 5	42½	35 3
13	115 4	28	53 5	43	34 9
13½	111 1	28½	52 6	43½	34 1
14	107 1	29	51 6	44	34 7
14½	103 4	29½	50.8	44½	33 5
15	100 0	30	50 0	45	33 3
15½	96.8	30½	49 2	45½	33 0
16	93 8	31	48.4	46	32 6
16½	90 9	31½	47.6	46½	32 3
17	88 2	32	46.9	47	31 9
17½	85 7	32½	46.2	47½	31 6
18	83 3	33	45 5	48	31.3
18½	81.1	33½	44.8	48½	30 9
19	79 0	34	44 1	49	30 6
19½	76 9	34½	43 5	49½	30 3
20	75 0	35	44 1	50	30 0

(*c*) T waves (normal, inverted, juvenile pattern, etc.).

(*d*) RS-T segment deviation (slight, marked, location).

9. *Unipolar Limb Leads:* (*a*) Electrical position of heart (vertical, transverse, etc.).

(*b*) aV_R (normal pattern, late R′, upright T, RS-T deviation); aV_L (Q wave, inverted T, and RS-T deviation); aV_F (Q wave, inverted T, RS-T deviation).

Before making an electrocardiographic diagnosis, it is important to obtain the following data: the age of the patient, sex, body habitus, and pertinent clinical findings. The more information that is available, the more

accurate will be the electrocardiographic diagnosis and the more definitely will one be able to make or rule out certain diagnostic possibilities For example, inversion of T waves in CR_2, CR_3, and CR_4 may be normal in a child, but will be abnormal in the adult. RS-T segment deviations may be the result of myocardial infarction or coronary insufficiency, depending on the history of precordial and substernal pain, its duration and type of previous electrocardiographic patterns. Furthermore, toxic factors, pericarditis and digitalis medication may also produce such changes. The presence of RS-T segment depression with prolongation of the QT interval could be the result of hypopotassemia if there is a history of fluid loss by vomiting or diarrhea; in the absence of a causative factor for electrolyte imbalance, other causes for these alterations must be sought. These illustrate but a few of the benefits of an adequate history and clinical evaluation in establishing electrocardiographic diagnosis.

After perusal of the electrocardiogram and pertinent data, the following types of diagnoses may be made:

1. *Normal tracing.*
2. *Borderline Tracing:* This statement may be made if minor deviations are observed; for example, slurring of the QRS complexes, minor grades of axis deviation, low amplitude T waves, etc.
3. A diagnosis of *myocardial abnormality* may be made when there are definite electrocardiographic alterations which may be reversible and which by themselves are not significant of permanent heart-muscle damage. Examples are RS-T segment depressions or T-wave inversions, which are the result of transient, toxic, metabolic or other factors which will permit a complete return of the tracing to normal and a return of the cardiac alterations to normal after the transient episode. As an example of this, we have the T wave and RS-T segment changes due to electrolyte imbalance, toxic states, etc., which produce transient alterations in myocardial function but which presumably lead to no permanent impairment of the heart muscle following their correction.
4. Although the diagnosis of *myocardial damage* may be made on a single tracing, observation may be required over a period of months before it is definitely concluded that some electrocardiographic changes, such as inverted T waves, RS-T segment depressions, QT prolongation, bundle-branch block, extrasystoles, auricular fibrillation, etc., are the result of organic and irreversible changes in the heart muscle.

REFERENCES

1. Sigler, L. H · Am Heart J 15 146, 1938
2 Wolferth, C. C, Livezey, M M, and Wood, F C Am J M Sc 203 641, 1942.
3. Wolferth, C. C, and Wood, F C Am. J M Sc. 183·30, 1938
4 Wilson, F N, Hill, D G W, and Johnston, F B Am Heart J 9.596, 1934
5 Wilson, F N, Hill, D G W, and Johnston, F. B · Am. Heart J 10 889, 1935
6 Wilson, F. N, Hill, D G W, and Johnston, F. B: Am. Heart J 10 903, 1935
7 Wilson, F. N., Hill, D G W, and Johnston, F B Am. Heart J. 10 1025, 1935.
8. Wilson, F. N, MacLeod, A. G, and Barker, P. S · "University of Michigan Studies, Scientific Series," Vol X, University of Michigan Press, 1935
9 Wood, F. C, Bellet, S, McMillan, T M, and Wolferth, C C Arch Int. Med 52:752, 1933

10. Bellet, S., and Johnston, C. G : J. Clin. Investigation 8.725, 1934
11 Am. Heart J 15.107, 1938.
12. Standardization of Precordial Leads. Second Supplementary Report of American Heart Association Committee. Am Heart J. 25·535, 1943
13 Myers, G B., Klein, H A., and Stofer, B E.: Am. Heart J. 35:1, 1948
14 Einthoven, W . Pfluger's Arch. f d. ges. Physiol. 112:517, 1908.
15 Bazett, H. C · Heart 7.353, 1920.
16 Fridericia, L S : Acta med Scandinav. 53:469, 1920-1921.
17 Lewis, T : "The Mechanism and Graphic Registration of the Heart Beat," Shaw & Sons, Ltd , London, 3rd Edit , 1925
18 Einthoven, W.: Pfluger's Arch f. d. ges. Physiol. 99:472, 1903.
19 Wood, P., and Selzer, A : Brit. Heart J. 1:81, 1939.
20. Wolff, L , Parkinson, J , and White, P. D.: Am. Heart J. 5·686, 1930
21 Wolferth, C C , and Wood, F. C : Am. Heart J 8:297, 1933.
22 Pardee, H E B.· Arch Int. Med. 46·470, 1930
23 Willius, F. A : "Clinical Electrocardiograms. Their Interpretation and Significance," W B. Saunders Co , Philadelphia, 1929.
24 Fenichel, N M , and Kugell, V. H.· Am Heart J. 7:235, 1931.
25 Willius, F A , and Killins, W. A.: Arch. Int. Med. 40.332, 1927.
26 Edeiken, J , and Wolferth, C. C.: Am J. M. Sc. 188:842, 1934.
27 Eyster, J. A E , and Meek, W J : Arch Int Med 11:204, 1913
28 Wilson, F N , MacLeod, A. G , and Barker, P. S · Am. Heart J. 7:305, 1932
29 Herrmann, G R , and Wilson, F. N.: Heart 9:91, 1921.
30 Katz, L. N., and Wachtel, H : Am Heart J. 11:611, 1936.
31. Nahum, L H , and Hoff, H. E.: Am. Heart J 17:585, 1939.
32 Pardee, H. E. B : "Clinical Aspects of the Electrocardiogram," P. B Hoeber, Inc., New York, 1933
33 Bellet, S , and Dyer, W. W · Am. Heart J. 13:72, 1937.
34 Lewis, T , Drury, A. M , Illiescu, C. C., and Wedd, A M : Heart 9.55, 1921-1922.
35 Lewis, T , Drury, A. M., and Bulger, H. A : Heart 8:83, 1921
36 McMillan, T M , and Bellet, S : Am J. M Sc. 184 33, 1932. Unpublished observations of the authors
37 Bellet, S , Steiger, W. A , Nadler, C. S., and Gazes, P. C : Am J M. Sc In press
38 Bellet, S , Nadler, C S , Gazes, P. C., and Lanning, M : Am J Med 6 712, 1949
39 Katz, L N · "Electrocardiography," Lea & Febiger, Philadelphia, 1946
40 Scherf, D , Romano, F J , and Terranova, R.: Am Heart J. 36 241, 1948
41. Prinzmetal, M , Brill, I. C , Corday, E , Sellers, A. L , Flieg, W. A , and Kruger, H. E. J Clin Investigation 28.804, 1949.
42 Campbell, M , and Gordon, F. B : Quart J. Med 5·205, 1936.
43 Wolferth, C. C , and Margolies, A , J. Clin. Investigation 14.605, 1935
44 Jourdonais, L. F., and Mosenthal, H O : Am Heart J. 14:735, 1937
45 Starr, I , Jr : Am J M S [illegible]
46 R [illegible]
47 S [illegible]
48 L [illegible]
49 G [illegible]
50 [illegible]
51 [illegible] Potentials in the Left [illegible]
52 [illegible]
53. [illegible] E.: Am. Heart J 33.819, 1937.
54. Levine, H. D., Hellems, H R , Dexter, L , and Tucker, A. S : Am Heart J 37:64, 1949.
54a. Hecht, H. H.: Am Heart J. 32·39, 1946
55 Schlesinger, P., Benchimol, A. B., and Cotrim, M. R : Am. Heart J. 37.1110, 1949
56. Sodi-Pallares, D , Thomson, P., and Soberon, J.: Am. Heart J. 36·1, 1948
57. Kert, M. J , and Hoobler, S. W.: Am Heart J. 38:97, 1949.
58 Cremer, M : Munchen med. Wchnschr. 53.811, 1906
59. Myers, G. B , and Klein, H. A.: Am. Heart J. 35:727, 1948.

60 Nyboer, J., and Hamilton, J G M : Brit. Heart J. 2:263, 1940
61. *Rosenbaum, F. F., Hecht, H H, Wilson, F. N, and Johnston, F. D* · Am. Heart J. 29:281, 1945.
62. Nyboer, J : Am. Heart J. 22·469, 1941.
63 Herrick, J. B.: J A M.A. 59.2015, 1912.
64 Smith, F. M.: Arch. Int. Med 32:497, 1923.
65 Pardee, H. E B : Arch Int. Med. 26 244, 1920
66 Parkinson, J., and Bedford, D E.: Heart 14 195, 1928
67. Barnes, A. R , and Whitten, M. B · Am Heart J 5 142, 1929
68. Manning, G. W., McEarchern, C. G , and Hall, G E.: Arch Int Med 64·661, 122.1933.
69 Wood, F. C , and Wolferth, C C : Am Heart J 9:706, 1934
70 Wolferth, C C., Wood, F C , and Bellet, S : Arch Int. Med 56 77, 1935
71. Bellet, S , and McMillan, T. M. Arch Int Med 61 381, 1938
72 Wood, F. C , Wolferth, C. C., and Bellet, S Am Heart J 16 387, 1938
73 McGinn, S , and White, P D J A M A. 104 1473, 1935
74 Barnes, A R . Proc Staff Meet , Mayo Clin 11 1, 1936
75 Soskin, S , Katz, L N , Strause, S , and Rubinfeld, S H Arch. Int Med 51. 1933
76 Bellet, S , Freed, H , and Dyer, W W : Am J M Sc 198 533, 1939.
77 White, P. D., and Mudd, S G · J Clin Investigation 7 387, 1929
78. Swift, H. F.: J A M A 92 2071, 1929
79 [illegible] J 31 806, 1928
80. [illegible] Clin Investigation 14 497, 1935
81 [illegible] Am Heart J 6 696, 1931
82 [illegible] Arch Int Med 60 1016, 1937
83 Nathanson, M. N · Arch Int Med 42 23, 1928.
84. Stecker, R. M : Am Heart J. 4 545, 1929
85 Gouley, B : Unpublished observations
86 Weiss, S : Tr A Am Physicians 51·341, 1936
87 Gelfand, D., and Bellet, S Med Clin North America 33 1643, 1949
88 Feil, H : Am. Heart J 11 183, 1936
89 Ellis, L. B , and Faulkner, J M. New England J Med 220 943, 1939
90. Weir, Capps, Ferris, and Murritt· Arch Int Med 58 407, 1936
91. Hegglin, R P., and Holtzman, M : Ztschr. f. klin. Med. 132 1, 1937.
92 Einthoven, W.. Boston M. and S J 121 901, 1924
93 Marvin, N. M · Am. Heart J 4 21, 1928
94 Palmer, and White, P. D : Am. Heart J. 3.454, 1928
95. Levine, S A : "Clinical Heart Disease," W. B Saunders Company, Philadelphia, 3rd Edit , 1945
96 Einthoven, W : Lancet 1:858, 1912.
97. Korns, H. M.· Arch. Int Med 31·36, 1923.
98 Wolff, L., and White, P D Arch Int. Med 43.652, 1929
99 [illegible]
100 [illegible]
101 [illegible] t J 6·637, 1931
102 [illegible]
103 Gilchrist, A R : Quart. J. Med. 2 499, 1933
104 Carter, E P., and Faulkner, J M · Bull Johns Hopkins Hosp. 42 245, 1928
105. Hamburger, W. W., Katz, L N , and Saphir, O · J A.M.A 106 902, 1936
106 Missal, M., and Crain, R B. Am Heart J 11 611, 1936
107. Kossman, C. E , and Johnston, D F Am Heart J 10 925, 1935
108. Wilson, F. N., Johnston, F D , Cotrim, N., and Rosenbau, E F : Tr. A Am [illegible]
109. [illegible] ogram des gesunden und kranken [illegible]
110 [illegible]
111. Barnes, A. R., Katz, L. N., Levine, S A., Pardee, H E B , White, P D , and Wilson, F. N : J A.M A. 121 1347, 1943
112. Wilson, F. N , and Herrmann, G R · Heart 9 21, 1922.
113 Scherf, D , and Weissberg, J · Am. J M Sc. 201·693, 1941
114 Sigler, L. H : Am. Heart J 15 146, 1938.
115. Stewart, H J , and Bailey, R L· Am Heart J. 18·27, 1939

116. Wolferth, C C., Bellet, S, Livezey, M. M., and Murphy, F.: Am. Heart J. 29:220, 1945
117 Levy, R L, Bruenn, H. G, and Russel, N. G., Jr.: Am. J. M. Sc 197·241, 1939
118. Wilson, F N., Johnston, F. C., and Hill, I. G. W.: Am. Heart J 10:176, 1935
119 Wolferth, C C, Livezey, M. M, and Wood, F. C: Am Heart J. 21:215, 1941
120 Wolferth, C C, Livezey, M M, and Wood, F. C.: Am J M Sc 203:641, 1942
121. Wilson, F N., Johnston, F. D, Rosenbaum, F. F., Erlanger, H, Kowsmann, C. E, Hecht, H, Cotrim, N., deOliveria, R. M., Scarsi, R, and Barker, P. S · Am. Heart J 27 10, 1944
122 Scherf, D, and Weissberg, J Am J. M. Sc. 201:693, 1941.
123 Stewart, H. J., and Bailey, R. L.: Am. Heart J. 18:271, 1939
124 [illegible]
125 [illegible]
126 [illegible] 2nd Edit, 1946
127 Wolferth, C C, Livezey, M. M., and Wood, F. C: Am Heart J. 21·215, 1941.
128 Wolferth, C C, Livezey, M. M, and Wood, F. C.: Am Heart J. 21:215, 1941.
129. Groedel, F. M, and Borchardt, P. R.: "Direct Electrocardiography of the Human Heart and Intracardiac Electrocardiography," Brooklyn Medical Press, New York, 1948
130 Goldberger, E. "Unipolar Lead Electrocardiography," Lea & Febiger, Philadelphia, 2nd Edit, 1949.
131. Kossman, C E, Berger, A. R., Brumlik, J., and Briller, S. A.· Am Heart J. 35 309, 1948.
132. Hellerstein, H K, and Katz, L. N.: Am Heart J 36:184, 1948
133 Myers, G B, Klein, H A., and Stofer, B E: Am Heart J. 36:535, 1948
134 Klein, H A, and Myers, G. B: J Lab & Clin Med. 34:1618, 1949
135 Alvarez, M S Rev españ de cardiol. 2:1, 1948
136 Hecht, H H · Arch Int Med. 84:711, 1949.
137. Pardee, H. E B Arch Int Med. 46:470, 1930.
138 Goldberger, E Am. Heart J. 30·345, 1945.
139. Myers, G B, Klein, H A., and Hiratzka, T.: Am Heart J. 38:548, 1949
140 Myers, G B, and Klein, H. A: Am. Heart J. 37:374, 1949
141 Myers, G B, Klein, H. A, and Hiratzka, T.: Am. Heart J. 37 205, 1949
142 Myers, G B, Klein, H A, and Hiratzka, T.: Am. Heart J. 37:720, 1949
143 Wilson, F N., Rosenbaum, F. F, and Johnston, F. D: "Advances in Internal Medicine," Vol II, Interscience Publishers, New York, 1947.
144 Rosenberg, B, and Messinger, W. J.: Am Heart J. 37:267, 1949
145 Yater, W M, Brown, W. G, Fitzgerald, R P., Geisler, M. A., and Wilcox, B B: Am. Heart J 36:334, 1948.
146 Dack, S, Master, H. M., Horn, H, Grishman, A., and Field, L. E: Am J Med 7·464, 1949
147. Wendkos, M, and Logue, R B.· Am Heart J 31:711, 1946
148 Scherf, D. [illegible] 1948.
149 [illegible] 838, 1948.
150. [illegible]
151. [illegible]
152 [illegible]
153 [illegible] 863, 1937.
154 [illegible]
155 Wasserburger, R. H.: Am J Med 18·428, 1955.
156. Ziegler, R F: Electrocardiographic Studies in Normal Infants and Children. Springfield, Illinois, C C Thomas, 1951.
157. Prinzmetal, M, *et al*: Circulation 7:1, 1953.
158 Wilson, F. N., *et al*: Am. Heart J 27:18, 1944.
159. Lambert, J. Am Heart J 47:40, 1954
160 Nomenclature and Criteria for the Diagnosis of Diseases of the Heart and Blood Vessels, 5th ed, Mallon, New York, New York Heart Association, Inc, 1953.
161. Wilson, F. N, Johnston, F. D, MacLeod, A. G, and Barker, P. S: Am. Heart J. 9:447, 1934.
162. Frank, E., and Kay, C. F.: Circulation 9:724, 1954.

163 Einthoven, W, Fahr, G, and deWaart, A Pfluger's Arch f. d ges Physiol 150.275, 1913.
164. Duchosal, P. W., and Sulzer, R.. La Vectorcardiographie Basel, S Karger, 1949
165 Goldberger, E.: Unipolar Lead Electrocardiography and Vectorcardiography Philadelphia, Lea & Febiger, 1953
166. Myers, G B, Klein, H A., and Stofer, B E. Am Heart J. 35 1, 1948.
167 Grant, R P: Circulation 7 890, 1953
168 Battro, A, and Mendy, J C: Arch. Int Med 78 31, 1946.
169. Gelfand, D, Urbach, J R, Bellet, S, and Allison, W · Right Ventricular Hypertrophy Cardiologia 26 228, 1955
170 Gelfand, D, and Bellet, S.: J Philadelphia General Hospital 4 135, 1953
171. Wilson, F N, and Johnston, F D Am Heart J 16-14, 1938
172 Langner, P. H, Jr. Circulation 8:905, 1953

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The Ballistocardiogram

Introduction: When one fires a gun, the recoil kicks him in the shoulder, and, the bigger the powder charge, the greater the kick and the greater the impact of the bullet. Thus, reduced to its simplest terms, this is the thought behind the group of instruments called ballistocardiographs, which seek to assess the strength of the heart's contraction by recording the movement imparted to the body by the movement of the blood within it. The increasing interest in this subject stems from the belief that the records provide information concerning the physiological aspects of cardiac function of a type not duplicated by the methods of cardiac examination available to clinicians hitherto.

History: In 1877, J. W. Gordon,[1] suspended a bed from the ceiling on ropes and obtained a record of its motion synchronous with the heartbeat. In 1905, Yandell Henderson,[2] built an elaborate suspended table and published a few records, realizing that they were related to the cardiac output. In 1913, a New York clinician, Thomas Satterthwaite,[3] obtained a fairly good ballistocardiogram from a patient sitting on spring scales. In 1922, two Englishmen, Heald and Tucker,[4] obtained records from a suspended platform, but the electrical method they used did not record the direction of the deflection so their records cannot be compared with ours. In 1928, the German geophysicist Angenheister[5] published a few records obtained when normal subjects lay on a table beside his seismograph. Finally, in 1933, a Swedish physiologist, Abramson,[6] published good records obtained with a beautifully constructed chair. The modern era may be said to date from 1939, when the record received its present name and systematic studies, both clinical and experimental, began.[7-37]

INSTRUMENTS

The problems of instrumentation have been receiving increasing attention in recent years and considerable progress has been made in rendering the diastolic portion of the record free of artifacts. However, all the various technics now in use in the clinic do not yield records identical in contour; nevertheless the different contours produced by the different technics have a basic mathematical relationship with one another.

Resisted Tables: In these instruments the movement of the table on which the subject rests is resisted by a strong spring.[7,8] The tables should be made as light as possible and the supporting framework must be

extremely strong. Short suspension, electrical amplification, and visual recording are usually employed today. These instruments have proved most satisfactory for clinical work. They are easy to operate and maintain, and they can be readily calibrated by a suspended weight. Normal breathing does not interfere with the record. The reproducibility is very striking.

The chief theoretical objection to resisted tables lies in the movement between subject and table which takes place to some degree even though the heels are firmly pressed against the footboard. A recent addition to the technic reduces this error. A sheet of rubber-like material, sold to prevent small rugs from slipping on a polished floor is placed between table and subject, and the subject tightens himself by placing his heels against the footplate with his knees flexed and then extending his knees. Fig. 1 shows such records.

Low Frequency Tables: In these instruments movement of the table is unopposed or opposed by very weak springs. Additional damping is added in amounts which vary in the different technics. These tables, if made very light, have the advantage that movement of the subject relative to the table is minimized. In Nickerson's apparatus,[9] the first of the modern era, displacement was recorded. In this technic, respiratory movements have a larger effect on the record than do forces coming from the heart, so most subjects must hold their breath before a good record of the latter can be secured; this is a serious disadvantage for clinical work, because differences in the position at which the breath is held influence the size and often the contour of the record. This disadvantage was overcome by von Wittern,[10] the first to devise an electric accelerometer adequate for the purpose. By recording acceleration he secured records in which normal breathing did not interfere. The record thus obtained is one of force and theoretically should be identical with that from resisted tables if both methods were perfect;[10] with present technics, the two types of records are certainly quite similar but probably not identical. Elsbach,[11] using a low frequency instrument designed by Burger,[12] has secured simultaneous records of displacement, velocity, and acceleration in a clinical study.

The recent developments in low frequency instruments are extremely promising. They have theoretical advantages, but it appears that the electric equipment required will have to be much more delicate and elaborate than that used in resisted tables. The calibration of acceleration records from low frequency tables will probably be more difficult than that of displacement records from resisted tables.

The Direct Body Record: The simplicity of this technic, first devised by Dock,[13] has been a major factor in the wide spread of interest in the field. In the original method the subject lay on a rigid surface with his heels slightly elevated and with a bar across his shins; motion of this bar relative to the rigid surface was recorded. In the original technic, velocity was picked up by a coil and magnet system and the aim was to integrate this to a record of displacement by means of a condenser. However, the condenser originally used for this purpose did not altogether accomplish it, so many papers in the earlier literature show records which fall between

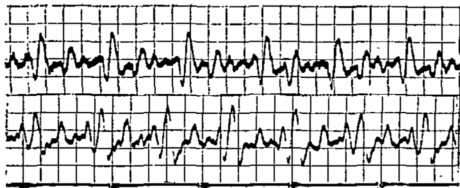


FIGURE 1. Ballistocardiograms of two normal subjects taken with resisted table by recent technics The top record is of S S a healthy young woman aged twenty-two years Note the short or absent K wave and the sharp definition of the diastolic complexes The lower record of a healthy adult aged sixty years shows a deeper K wave but a well marked diastolic complex. These records should be compared with the top record of Fig 4 taken by our original technic to demonstrate the improvement in the diastolic part of the record which, by the newer method, no longer looks like a series of waves in phase

RELATIONS BETWEEN BALLISTOCARDIOGRAMS

RECORDING DISPLACEMENT VELOCITY ACCELERATION

IMPROVED DIRECT BODY

SMITH

ARBEIT

ORIGINAL DOCK DIRECT BODY

DOCK "DIAGNOSTIC"

HIGH FREQUENCY TABLES

STARR

LOW FREQUENCY TABLES

VON WITTERN

BURGER

NICKERSON

RECORDING DISPLACEMENT ACCELERATION

VELOCITY

FIGURE 2. Designed to show diagrammatically the relation between the typical ballistocardiogram of a healthy person taken by various technics. Each of the diagrams is the ballistocardiogram of a single cardiac cycle For further description see text.

displacement and velocity. There is difficulty calibrating records of this type and most doctors using these simple methods do not attempt it. In the absence of a calibration, abnormalities of amplitude cannot be detected, but changes in contour are readily detected and this is a large and important part of the field. Smith *et al.*[14,16] have improved the method by using a lighter shin bar and a larger condenser to give true records of displacement. This instrument is calibrated at the factory, but the method is too difficult to permit the routine calibrations which are such a safeguard in clinical work. Arbeit's instrument[15] obtains much similar records by different electrical means.

Both these authors[15,16] have interested themselves not only in displacement records but also in records of the velocity and acceleration of such a shin bar, in the hope that clinical abnormalities of importance would be made more obvious by such means.

Bixby and Henderson[17] have demonstrated that a good displacement ballistocardiogram, readily calibrated, can be secured by using a microscope to magnify the movement of a light beam. Indeed, any doctor can observe the ballistocardiogram for himself by focusing his microscope on a pointer attached to a light bar placed across the shins of any subject lying on a rigid surface. Unfortunately, the movement is too rapid to permit the individual waves of the ballistocardiogram to be identified by the unaided eye, but the overall magnitude is easily ascertained by placing a micrometer in the eyepiece.

Relation Between Records Secured by Various Methods: The relation of all these records to one another is given diagrammatically in Fig. 2. The displacement record from high frequency tables, the improved displacement records taken directly from a shin bar, and the acceleration records of low frequency tables are all essentially records of force and, although probably not identical because of technical deficiencies, they bear a strong resemblance to one another and they have been aligned vertically in the center of the figure. Looking to the left of the figure, in the direction of integration, one observes the results secured by recording velocity and displacement in low frequency tables, and notes that the waves broaden in such records. Looking to the right, in the direction of differentiation, one observes the results secured in direct body records when velocity and acceleration are recorded, and notes that the waves narrow. The record secured by the original Dock technic falls between displacement and velocity records taken by newer shin bar technics.

Additional factors concerned with technic enter into the shape of the records. Dr. E. W. Bixby [illegible] between the subject and a resisted [illegible] from firm contact with th[illegible] head and heels, the waves of the record broaden, and so the form "moves to the left" in Fig. 2, as if such error of technic tended to integrate the record. For the same reason it seems likely that in the direct body methods, since the restoring force, the spring in the body tissues, must vary from subject to subject depending on habitus and the amount of obesity, records taken from a shin bar would vary from true records of

force by an amount which differed somewhat from person to person. So Fig. 2 is an inexact presentation of the relationship between records secured by the various technics, but it is illuminating none the less.

One cannot say at this time that one type of record will be found more valuable to clinicians than another. Indeed, theoretically, since the records are mathematically related one to another, given any record shown in Fig. 2, one could derive every other record in the figure. Were it not for the technical deficiencies of the various technics, if one knew what to look for, he should be able to see in any one record a large part, if not all, of the information that the others contain. The force record most appeals to me, and it has been the most widely used.

Other Types of Ballistocardiographs: Vertical instruments recording ballistocardiograms from patients standing or sitting have been in use for many years.[18] They are not as satisfactory as horizontal instruments because of the increased difficulty of isolating them from motion in the building, and the fact that many sick persons are likely to tremble when upright, ruining the record. Studies of transverse and sagittal records are beginning to appear,[19,20] and three dimensional "vector" recording has commenced.[46] A torsion ballistocardiograph, recording rotatory forces has also been built.[21] Most interesting records have been secured from subjects lying on a platform floating in a pool of mercury,[22] a technic of great theoretical interest even though a practical clinical instrument can hardly be expected to emerge from it.

My clinical experience with records from resisted tables far exceeds that with records taken by other methods, so the remainder of this paper will be chiefly devoted to an analysis of the findings secured by this means. But there is little doubt that similar conclusions could be drawn from the other technics.

THE RECORD AND ITS GENESIS

Our technic is as follows. We do not insist that patients be in the basal state but we prefer not to take records within two hours of a meal. The subjects are allowed to rest for fifteen minutes on the table. Before taking the record the operator assures himself that the subject's heels are in firm contact with the footplate. Each record is calibrated by allowing a 280 Gm weight to displace the base line temporarily.

Inspection and Measurement: The record is first inspected for abnormalities with the knowledge that any movement made by the patient will cause distortion. So artifacts are common, but with experience they can be identified at a glance, the rule being that no abnormality which is not regularly repeated is worthy of attention. Abnormalities of form, if present, do not follow one another in a procession of identical complexes. The form changes with the respiratory cycle and one looks at corresponding positions in other cycles for similar complexes. If there is any doubt of the normality of the amplitude, we select typical large and small complexes of the respiratory cycle and measure the depth and height of the I-J waves, and often the duration also, to permit estimations of the shaded areas in Fig. 3.

Normal Records: The extraordinary similarity of the records secured from healthy young adults is one of the most striking features of the field. Fig. 1, 3, and 4 show typical examples, and Fig. 3 gives the letters usually assigned to the various waves. Respiratory variation is always seen, the size of the complexes increasing during inspiration. The position of systole,

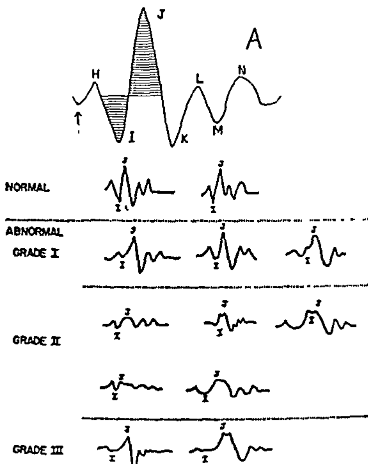


FIGURE 3. Normal and abnormal forms of ballistocardiograms At the top an enlarged normal record is shown and the letters assigned to the waves are given The shaded area indicates that part of the record which is measured for the calculations of cardiac output and for estimating the normality of the size of the complexes. The arrow indicates the beginning of the Q-R-S complex of the electrocardiogram. Below on a smaller scale, various types of normal and abnormal records are shown. (Am. Heart J. 25:81, 1943, Am. J. M. Sc. 212·591, 1946)

and the identity of each wave can be recognized at a glance. As technic has improved, the K wave has shortened and the diastolic complex has taken on greater clarity. The second of the smaller normal complexes shown in Fig. 3 is more typical of the record of healthy young adults, when taken by the best of the modern methods, than is the first.

Abnormalities of Amplitude: Records may be abnormal because they are too large or too small in amplitude, or because their contour is abnormal. The former two can be detected only in records which can be calibrated. Quantitative standards of many types are available,[21] some empirical, some aimed at estimating cardiac output.[27] I use a screening test[23] developed

from my original series of normal subjects, studied in 1937-8-9, after all those who developed cardiac disease in the following years had been subtracted. These standards[23] are based on the sum of the square root of the altitudes or areas of typical large and small complexes of the respiratory cycle. Men and women are considered separately. By means of a table the normality of any subject can be determined without a calculation.[23] It must be remembered, however, that differences in apparatus and technic may affect the quantitative aspects of the record. Everyone interested in the quantitative aspects of the field should assure himself that the average amplitude of the records secured on his healthy young adults does not differ significantly from my experience, before using my normal standards.

Abnormalities of Form: There are so many varieties of abnormalities of form that the detailed description of abnormal ballistocardiograms is often very difficult. Fig. 3 shows various types diagrammatically, better than they could be briefly described. Fig 4 shows several types of abnormal records.

Unlike the electrocardiogram, when the ballistocardiogram is abnormal *in form*, its contour usually changes from beat to beat with the respiratory cycle, the most abnormal contours occurring in the smallest complexes at the end of expiration. In many records only one or two of the smallest complexes of this cycle are abnormal in form, all the rest being normal. This is an interesting example of Starling's law, for abnormality first manifests itself at that part of the respiratory cycle in which cardiac filling is at a minimum. In repeated records taken in aging patients, I have seen the smallest complex of the respiratory cycle become abnormal first, and later the abnormality spread to other complexes So I believe that the proportion of normal to abnormal complexes is an important indication of the severity of the cardiac abnormality.

Another useful graduation of severity was proposed by Brown.[8] In his Grade I the ratio of the amplitude of large to small complexes in the respiratory cycle was abnormal, the small being less than half the amplitude of the large. This must be interpreted with caution because overbreathing from apprehensiveness or excitement can cause the same effect. In Grade II, the smaller complexes are abnormal in form, the larger remaining normal. In Grade III, the abnormality has spread throughout the record. In Grade IV, the record is so distorted that systole cannot be identified with confidence without a simultaneous electrocardiogram or pulse record.

Genesis of the Record: There is agreement concerning the genesis of the main systolic waves of the normal ballistocardiogram, and a somewhat oversimplified description is as follows. The footward I wave, beginning at or near the beginning of ejection is caused by the recoil of the body to the headward expulsion of blood by the heart. An instant later the onrushing blood strikes the arch of the aorta and the curve of the pulmonary artery and the headward movement of most of it is arrested, and immediately thereafter the blood in the aortic arch is accelerated footward, both factors combining to cause a headward impact, the J wave, which is the largest wave on the normal record. In the older records an artifact contributed to the size of the K wave, a remainder seen in some modern ballistocardiograms is to be attributed to forces generated when the long column of blood in the thoracic and abdominal aorta is decelerated. The following

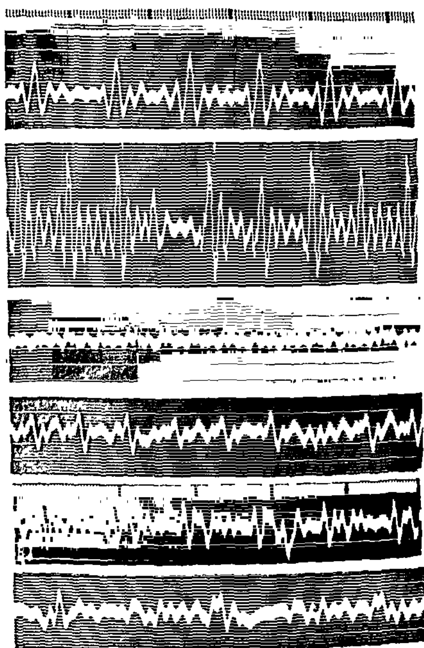


FIGURE 4 Normal and abnormal ballistocardiograms taken by the author's original technic The time record at the top applies to all records; the longest interval is one second. All records were made after a fifteen minute rest in the horizontal position Headward is up The reproduction is actual size *Top*, Dr T., age twenty-five, 6 feet 2 inches, 180 pounds, a normal subject. This record is normal *Second*, W B., age sixty-eight, 5 feet 6 inches, 111 pounds. Hyperthyroidism Basal metabolic rate + 78. The cardiac output is calculated to be 148 per cent above average normal. An extrasystole, moving less blood than the other systoles, [illegible] normal in form so the myocardiur [illegible] fifty-one, 5 feet, 119 pound [illegible] oris. The systolic impacts [illegible] inty. *The* record indicates a very severe myocardial abnormality. *Fourth*, L. S., age sixty-four, 4 feet 9 inches, 123 pounds, B.P. 195/85. Hyperthyroid, B.M.R. + 29.

headward L wave is more conspicuous in records from Nickerson-type tables, and from direct body instruments of the Dock type than in those from resisted tables, but the diastolic waves of normal subjects are always small in comparison with the systolic waves.

Attempts to relate the small diastolic waves to physiological events in diastole[13] have seemed to me premature, but as improvements in technic are clearing up this part of the record I have little doubt that our knowledge of the genesis of diastolic waves will increase rapidly.

Many factors enter into the origin of the H wave Usually absent in auricular fibrillation and when in heart block the auricle does not beat at the usual time, it has naturally been attributed to auricular forces. But H waves are seen in some cases of auricular fibrillation and the very large H waves seen in some cases of coronary heart disease lack a clear explanation. Possible factors are forces from mitral or tricuspid regurgitation, abnormal movement of blood within the heart due to bulging of a weak spot in the wall, and an abnormally sudden arrest of the venous blood column when diastole is terminated

Mathematical Studies: On the assumption that the body as a whole behaves as a simple oscillator, attempts have been made to discover its vibration properties and so to estimate the distortion of forces passing through the body.[10] Other attempts have been made to calculate the forces originating the ballistocardiogram by elaborate mathematical treatment of the curves themselves.[24] These lead to a general agreement that resisted tables, when displacement is recorded, and also low frequency tables, when acceleration is recorded, give records of cardiac force, although the records are not altogether free of distortion

The Experimental Approach: Experiments in which systole was simulated at necropsy with the subject on a ballistocardiograph[25] yield results which indicate that in records from resisted tables it is the square root of the amplitude which is most closely related to cardiac forces.[26] Two minor qualifications to this rule have developed,[27] differences in the height of the blood pressure and the size of the subject affect the relationship between the amplitude of the record and cardiac force, but the influence of these disturbing factors is so small that they can be neglected in clinical work at this time.

The square root of the ballistic amplitude, multiplied by a factor related

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This record is very abnormal in form No normal complexes are seen The I wave is absent or greatly diminished in size, the J wave is low in the smaller complexes K is deep, and the J K downstroke the most prominent feature of the record. The record indicates a severe abnormality of myocardial function doubtless due to [illegible]

presence of the aneurysm causes the impact from the left side to lag *Sixth,* P K, age fifty-three, 5 feet 5 inches, 198 pounds, B P 225/125 Essential hypertension Heart not enlarged by orthodiagram. She feels well and has no complaints The record shows one normal complex in each respiratory cycle In the others, the I waves are small and J is flattened or notched Due to increased resistance in the periphery the impacts from the left side lag behind those of the right. This heart is showing signs of being unequal to its task. (Harvey Lect., 1946-1947)

TABLE 1

OCCURRENCE OF BALLISTOCARDIOGRAMS ABNORMALLY SMALL IN AMPLITUDE

Group	*Frequency of Hypokinemia Among All Cases in This Group*
Moribund patients	All
Hemorrhagic shock	All ?
In congestive heart failure	Most
Valvular heart disease not in failure	About ½
Coronary heart disease.	
Chronic angina pectoris	Many
Soon after infarction	About ½
Hypertension	About ⅓
Endocrine diseases	
Myxedema	All
Pituitary or adrenal	Many
Convalescence from severe febrile disease	Some

to the duration of ejection, affords a rough measure of cardiac output when the record is normal,[27] but when the record is abnormal, the method cannot be relied upon.

In these cadaver experiments[27,45] when a strong heartbeat is simulated by an injection into the great vessels initiated by a powerful blow, a ballistocardiogram normal in form and amplitude results. When a weak beat is simulated by a weak blow, the I wave diminishes or disappears and J is small and retarded, the K wave becoming more conspicuous. If the aorta and pulmonary artery are injected asynchronously, the J wave is split. We now know how to reproduce experimentally many of the abnormalities seen in the clinic.

CLINICAL STUDIES

Results Secured in Healthy Persons: Healthy young adults give normal records almost without exception and this is an impressive feature of the field. As age advances, even though health commensurate with one's age is maintained, the average amplitude of the records diminishes. The contour changes also, the amplitude of the I and J waves diminishing, while K becomes more conspicuous.[28] Besides this normal effect of aging, an increasing proportion of truly abnormal records is found as life advances even though the ordinary clinical studies are negative. The significance of these will be discussed later.

Results Secured as Disease Develops: Deterioration of the record as disease develops[29] has been demonstrated again and again as age and disease overtake the members of the group I have been following for almost twenty years.

Results Secured in the Sick: Table 1 shows the occurrence of records, abnormal because they are too small, in the commoner clinical conditions.

TABLE 2

OCCURRENCE OF BALLISTOCARDIOGRAMS ABNORMALLY LARGE IN AMPLITUDE

Group	*Frequency of Hyperkinemia Among All Cases in This Group*
Healthy persons	A very few
Hyperthyroidism without cardiac complications	Almost all
Aortic regurgitation	Almost all
Extreme emaciation	About ¾
Patent ductus arteriosus	Most
Peripheral A-V aneurysms	Few
Anemia	About ¼
Febrile disease tested late in the course	A few only
Hypertension	A very few
Pulmonary.	
After pneumonectomy	4 of 5 cases
In chronic disease	Many

Table 2 gives similar information about records abnormal because they are too large. Table 3 shows the occurrence of records abnormal in contour. To summarize, the great majority of cases of manifest heart disease have abnormal ballistocardiograms, but by no means all. Many cases of those diseases in which heart disease is a frequent complication also give abnormal records. In addition, abnormalities of form also occur frequently in patients in the latter years of life who suffer from a large variety of diseases not known to affect the heart.

Changes in the Record of Individuals: Changes in the record with changing conditions of disease are often conspicuous. Records secured during an attack of angina[30,31,33] are accompanied by a marked abnormality of form, a disorderly type of change, suggesting that the usual fine coordination of the cardiac contractions has been lost, rapid improvement accompanies the relief of pain brought about by nitrites Records taken during the acute stage of a cardiac infarct are usually but not always abnormal, and they may or may not improve slowly in convalescence. But especially in the younger group, a typical clinical picture and strong electrocardiographic evidence of cardiac infarction are not necessarily accompanied by an abnormal ballistocardiogram taken with the patient at rest. In congestive failure the distorted ballistocardiogram of small amplitude often improves as the patient responds to therapy, but the typical picture of congestive failure may be accompanied by a ballistocardiogram altogether normal in form. I have had one patient with advanced pulmonary disease who, in congestive failure for the fifth time, had a ballistocardiogram not only normal in contour but abnormally large in amplitude. Undoubtedly such cases belong to the group now called high output failure. Arrhythmias like auricular fibrillations are usually accompanied by ballistocardiograms markedly abnormal in contour, but this is not always the case. I have

TABLE 3

FREQUENCY OF BALLISTOCARDIOGRAMS ABNORMAL IN FORM IN DIFFERENT CLINICAL CONDITIONS (EXPERIENCE FROM 1937 TO 1947)

Diagnosis	*Total No. Cases Studied*	*No Cases with Abnormalities of Form*	*Per Cent with Abnormalities of Form*
Hypertension	176	69	39
Hyperthyroid	112	13	12
Hypothyroid	22	2	10
Organic Heart Disease:			
Rheumatic	95	43	45
Coronary	127	63	50
Luetic	21	6	29
Congenital	34	2	6
Pericarditis	12	4	33
Type in doubt	14	3	21
Conduction defect in ECG (primary classification in doubt):			
A-V block	6	6	100
Intraventricular block	17	4	24
No manifest heart disease:			
Cases from the Medical Service:			
Pulmonary disease	37	7	19
Anemia	30	2	7
Severe diabetic acidosis	3	3	100
Others	...	7	...
Cases from the Surgical Service:			
Before operation–Colonic lesions	13	7	54
Gastric lesions	12	4	33
Cranial lesions	11	2	18
Biliary tract lesions	17	4	24
Herniae	31	2	6
After operation—(from 1 to 10 days post-operative)	63	39	62

many records taken in patients with this arrhythmia that are altogether normal except for the spacing in time and the disappearance of the H wave; so it is not the arrhythmia itself that causes the abnormality of cardiac contractions but the myocardial deterioration that so often accompanies it. Extrasystoles occurring too soon after the previous beat to allow proper filling are likely to give small ballistocardiograms, but the next normal beat coming after a prolonged diastole is likely to give a large one. In heart block the isolated auricular beats produce a recognizable series of small impacts, and the best ventricular complex is likely to accompany the ventricular contraction following an auricular beat in its usual position.

In older people any surgical procedure is often followed by temporary deterioration of their ballistocardiogram.[32]

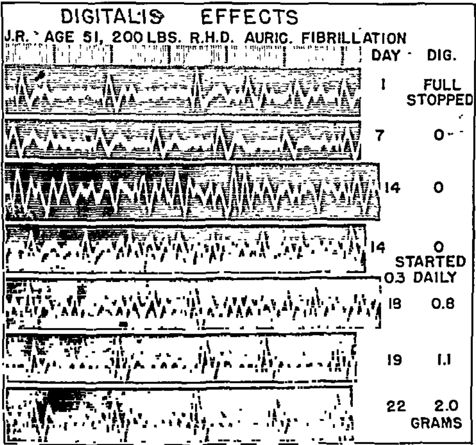


FIGURE 5 Digitalis effect in a patient with rheumatic heart disease and auricular fibrillation who was not in failure

The patient entered the hospital under the influence of digitalis. The first record indicates reasonably good myocardial function as most of the systolic complexes are normal in form, despite their irregularity in time Digitalis was stopped, and seven days later the complexes were smaller but they were still mostly normal in form. Fourteen days after admission, the myocardial condition had greatly deteriorated. The ballistocardiogram had become greatly confused and the systolic complexes varied both in time and shape, the majority being highly abnormal. Two parts of the record taken this day are shown Digitalis was again started. Four days later the record showed little improvement, but the following day, a total of 1 1 Gm. of digitalis having been given over the five-day period, the improvement was manifest and the form of all the complexes was normal. The last record shows that the improvement continued. The last two records have large, well-formed normal complexes, contrasting, a form with rather flat diastolic waves characteristic of patients with auricular fibrillation who have responded well to digitalis

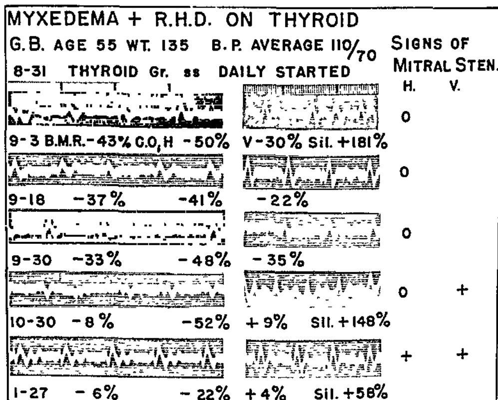


FIGURE 6 A patient with myxedema, later proved to have rheumatic heart disease as well, given thyroid. A comparison between the effect on the basal metabolic rate (B M R) and on the circulation (C O) in the horizontal (H) and vertical (V) positions

Under the influence of the thyroid, the B M.R returned to normal more rapidly than did the horizontal circulation During the period near 10/30 the discrepancy was mark
symptoms, especially
hesitation the admini
correct one, for the circulation returned to normal and the symptoms disappeared

The right side of the figure shows vertical ballistocardiograms and the presence or absence of a presystolic murmur. This was not heard in the initial examinations, all of which were conducted with the patient horizontal On 10/30 the murmur could be plainly heard when the subject stood but it was inaudible when she lay at rest On 1/27 this murmur was easily heard in both positions The correlation between the size of the ballistocardiogram and the presence of the murmur is evident Obviously this murmur appeared only when the circulation traveled through the narrowed valves with sufficient rapidity

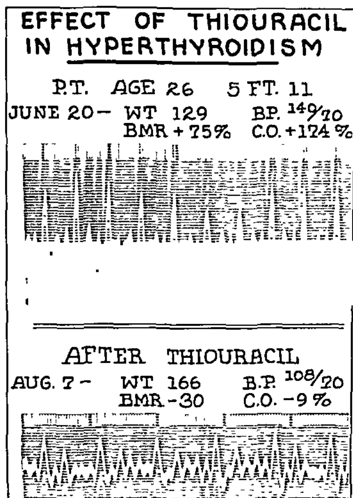


FIGURE 7 The effect of thiouracil on a patient with severe hyperthyroidism.

Effects of Therapy: These are often extremely striking. Fig. 5 shows a typical digitalis effect, Fig 6 and 7 the effect of therapy in myxedema and hyperthyroidism. I have seen similar improvement follow therapy in many other cases.

Nitrites may restore the form to normal or cause improvement in an abnormal record even though the patient is not having angina or known to be suffering from coronary heart disease.[33] Occasionally these drugs cause deterioration of the record. I have records of a case of syphilitic heart disease in which the improvement after penicillin and other measures was spectacular. Drugs which lower the blood pressure in hypertension often cause improvement in the record, but by no means always.

The modern cardiac operations may be followed by marked deterioration of the record in the postoperative period and I believe that they have a greater immediate adverse effect on cardiac function than has been usually realized. But many patients recover from these untoward effects and the final result may show gratifying improvement over the preoperative state.

Special Tests: There is every reason to think that myocardial abnormalities not detected at rest might be demonstrated by subjecting the heart to stress, and because of the ease of securing repeated observations, the ballistocardiograph is well suited to this purpose. Although records cannot be secured during exercise, they can be taken immediately after it is over, so the effect of exercise on the record of any patient[34,35,38] can be discovered by any physician possessing an instrument. In some clinics this is done routinely. Abnormalities are often brought out by an exercise test when the record of the subject at rest is normal.

But records taken soon after exercise are far more subject to artifacts than are records taken at rest, so there is much to trip the unwary doctor. Let me repeat the rule, "No abnormality that is not regularly repeated is worthy of attention." Occasionally the record will be found to have improved after exercise. I interpret this unexpected finding as indicating that some defective hearts, subjected to physiological stimulation by the exercise, respond by more normal contractions, as abnormal hearts so often do after a stimulant drug.

Tests of cardiac function during anoxemia often yield interesting results,[36] and, as the patient's position is unchanged while anoxemia is induced, artifacts are less likely to appear in the record than in tests made after exercise.

Deterioration of the record after smoking[35,37] is so frequent in those with coronary heart disease diagnosed by the usual clinical criteria that one wonders whether this might not be properly used to aid in the identification of this condition. Indeed, the responses of the heart to many drugs may well be developed into methods of testing for its functional capacity and limitations.

UTILITY OF THE BALLISTOCARDIOGRAM

The ballistocardiograph is a physiological instrument designed to make readily available to clinicians information about certain fundamental aspects of the heart's function, especially its strength or weakness. Changes in cardiac function may or may not accompany the various anatomic and descriptive cardiac abnormalities that were the concern of the pathological and descriptive schools, and that form the basis of most cardiac diagnoses made today. In my opinion little help will be gained from the ballistocardiogram in making cardiac diagnoses of the anatomic type. Those whose range of vision is limited to the conceptions of the past can be expected to see little virtue in the instrument. The chief information it gives is of a kind to which they are not accustomed.

It is nevertheless true that one may get some help in making certain anatomical diagnoses. In wide open aortic regurgitation the huge amplitude accompanied by a slow rate is very characteristic. Abnormality in the H wave, I wave, or H-I segment is very characteristic of mitral valvular disease;[40] from the positions of such abnormal notching Henderson[40] has learned to approximate the height of pulmonary artery pressure. Brown's discovery of the association of a shortened K wave with coarctation of the aorta[8] and its lengthening after surgical correction of the narrowing has been amply confirmed and is still valid despite the fact that improvements

of technic are themselves shortening this wave and the original criteria can no longer been applied to records of the newer type.[22] I have records in which a shortened K wave was produced after a surgeon had inserted a ball valve into the descending aorta in an attempt to treat aortic regurgitation. As always, it is the disturbance in function caused by the lesion, not the presence of the anatomical lesion itself, that is reflected by the changes in ballistocardiograms.

Everyone having clinical experience with ballistocardiograms soon gets the impression that they permit physiological distinctions not brought out by the usual clinical study available hitherto. In some cases of undoubted cardiac infarction, myocardial function is hit hard, in others, perhaps because the lesion is smaller, the resting record is not affected at all. Certainly such distinction seems well worth making, as do those concerned with the amount of myocardial recovery attained during convalescence from such accidents. Similar distinctions can be made about cases of angina pectoris. In hyperthyroidism one gets the impression that myocardial involvement is more frequent than was suspected when the evidence was limited to the old criteria. In rheumatic heart disease, especially in young persons, one often is encouraged to find that myocardial function is normal despite valvular lesions. Elderly persons apparently in good health are sharply divided by ballistocardiographic findings. With the ballistocardiogram before him the physician often gets a rather different impression of his patients One does not use the ballistocardiogram to make well-known diagnoses with greater confidence, but to gain additional information about the hearts of the patients

Concepts such as cardiac fatigue, diminished cardiac reserve, myocardial weakness, and heart failure have been in the past speculations so vague that they have had little meaning Judged by the ballistocardiogram they at once acquire meaning; indeed, they have objective demonstration.

The ballistocardiogram will also aid in the interpretation of elevations in blood pressure, for this pressure depends not only on the constriction of the peripheral vessels but also on the output of the heart. The ordinary case of essential hypertension in good condition shows a ballistocardiogram that is either normal or of small amplitude, but in certain emotional states hypertension is accompanied by ballistocardiograms of large amplitude; thus, although the pressure readings may be similar, great differences in physiological mechanisms are disclosed

The ballistocardiograph seems well suited to aid one in securing objective evidence of situations beneficial or harmful to the patient whose heart is suspected of being abnormal. Thus digitalis causes extraordinary improvement in the records of some patients, but in others marked deterioration of a previously normal record has followed its use. One wonders how often the busy physician accurately estimates the effect of this potent agent on the patient before him.

As well as identifying situations that produce benefit, the physician must concern himself with those that cause harm, and the ballistocardiogram can also be used for this purpose. The deleterious effect of tobacco[37,38,39] on the record came to me as a complete surprise. In healthy young persons, smoking produces no effect on the record, but, in some

persons beyond middle age, the temporary deterioration of the record produced by smoking one cigarette may reach a degree that suggests approaching weakness and incoordination of cardiac contraction seen when a patient subject to angina pectoris has a spontaneous attack on the table Although the fact that tobacco can occasionally induce attacks of angina is well known, the profession has had no way of detecting, and has underestimated, the deleterious effects that can occur in the absence of pain. These are very definite in many patients with the clinical picture of coronary heart disease, and in many older people without definite evidence of this disorder by the usual clinical criteria; and one wonders whether the interdiction of smoking in cases showing such abnormal responses might not have as great a beneficial effect as in the closely related peripheral vascular diseases

Of great interest is the finding that many persons in the latter half of life have abnormal ballistocardiograms although they give no other clinical evidence of abnormality.[29,41,42] How should these cases be regarded? Several facts support the view that such a finding indicates coronary heart disease of a form too mild to produce the usual symptoms; first, the proportion of such cases found at different ages corresponds roughly to the proportion of cases showing coronary heart disease at necropsy at similar ages;[13] second, nitroglycerin restores the record to normal, or improves it, in a considerable number of these cases;[33] third, some of these cases have developed clinical evidence of coronary heart disease subsequently;[29,43] and fourth, in a few cases, eventually coming to necropsy, coronary heart disease was demonstrated.[32,43] So there seems little doubt that there is a relation between such cases with abnormal ballistocardiograms and coronary heart disease, although the data available at present do not permit one to say how close the relation is. It must always be kept in mind that the ballistocardiogram demonstrates physiological, not anatomical changes The skeletal muscles weaken as age advances, and this cannot be attributed to anatomical alterations in the supplying arteries. The aging heart may well weaken for a similar reason. Drugs and poisons profoundly alter cardiac function without causing lesions demonstrable at necropsy. One should not expect to find an anatomical lesion whenever the ballistocardiogram is abnormal, and to try to explain the weakening of age on the basis of anatomical lesions alone is greatly to over-simplify a problem of terrifying complexity.

Finally, we must discuss the prognostic value of the record and in this field the last word has not been said. Fig. 8 shows the result of my original study.[43] Cases in which abnormality of the ballistocardiogram preceded the development of manifest heart disease continue to come to my attention. I have reported two additional cases more recently[33,45] and have many more in my records. Friends keep informing me of similar experiences. But I also have records of several cases who developed coronary infarcts despite a normal ballistocardiogram at rest,[31] and I have many records of elderly people whose health continues to commensurate with their age, although their ballistocardiograms have been abnormal for a number of years. Nevertheless, when an abnormal record is found in an aging patient, otherwise in good health, the question must be raised whether preventive measures are not worth trying, even though their suc-

cess or failure will be hard to assess. The increasing evidence of the adverse effects of tobacco and high fat diets suggests that the interdiction of the first and the limitation of the second would be a logical regime to try.

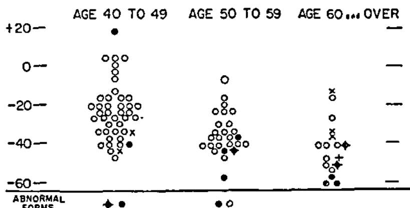


FIGURE 8 Comparison between the after-histories and the relative amount of the circulation, as calculated from the time-amplitude of ballistocardiograms taken in 1937, 1938, and 1939 The data are referred to the subjects' ideal weight The scale to the left is based, not on the data given here, but on the statistics of fifty-four healthy persons between twenty and thrity years of age Zero has been placed at the mean of this group The normal limits of this group, defined as twice the standard deviation, are ±29 per cent The different symbols indicate the after-histories· o remained well until 1947, • developed coronary heart disease; + died of heart disease, X died without developing heart disease (Am J M Sc 214 233, 1947.)

REFERENCES

1. Gordon, J. W. Anat Physiol. 11 533, 1877.
2. Henderson, Y: Am J Physiol. 14·287, 1905
3. Satterthwaite, T E: "Cardiovascular Diseases," Lemcke and Buechner, New York, 1913
4. Heald, C. B, and Tucker, W S Proc Royal Soc, Series B 93 281, 1922.
5. Agenheister, G, and Lau, E: Naturwis 16 513, 1928
6. Abramson, C: Skand Arch f Physiol 66 19, 1933
7. Starr, I., Rawson, A J, Schroeder, H A, and Joseph, N. R Am. J Physiol. 127.1, 1939.
8. Brown, H. R, Jr, deLalla, V, Jr, Epstein, M A, and Hoffman, M J: "Clinical Ballistocardiography," The Macmillan Co, New York, 1952.
9. Nickerson, J L., and Curtis, H J Am. J Physiol 142 1, 1944
10. von Wittern, W W. Am. Heart J 46 705, 1953
11. Elsbach, H: "Klinische Onderzoekingen met de laag—frequente ballistocardiograaph volgens Binger," Uitgeverig Excelsior s'Gravenhage, 1954
12. Binger, H C, Noordergraff, A., and Verhagen, A M W Am. Heart J. 46 71, 1953.
13. Dock, W., Mandelbaum, H, and Mandelbaum, R A · "Ballistocardiography," C. V. Mosby Co., St Louis, 1953
14. Smith, J. E, and Bryan, S Am Heart J 45 715, 1953
15. Arbeit, S R., and Lindner, N · Am Heart J 45:52, 1953.
16. Smith, J E, Lederer, L G, and Mandes, J C: Am Heart J 49 344, 1955.
17. Bixby, E. W., and Henderson, C. B: Circulation 8 578, 1953.
18. Starr, I, and Rawson, A. J: Am. J Physiol. 134.403, 1941

19. Scarborough, W. R , and others: Bull Johns Hopkins Hospital 87:235, 1950.
20. Morris, G. L., and Braunstein· Circulation 11:767, 1955
21. Reissmann, K. R., and Dimond, E. G : Circulation 8:585, 1953
22 Denchar, D. C , Talbot, S. A., and Scarborough, W. R.: Circulation 9.228, 1955
23 Starr, I . Circulation 11·914, 1955.
24 Nickerson, J L , and Mathers, J. A. L : Am Heart J. 47:1, 1954.
25 Starr, I., Schnabel, T. G , Jr , and Mayock, R. L.: Circulation 8:44, 1953
26 Starr, I , and Schnabel, T G , Jr : J Clin. Invest 33 10, 1954.
27 Starr, I · J. App Physiol , 8·315, 1955.
28 Scarborough, W R , and others. Am. Heart J. 45:161, 1953
29 Starr, I , and Hildreth, E A · Circulation 5·481, 1952.
30 Singewald, M. L.· Ann. Int Med 41:1124, 1954
31 Starr, I · J A.M A 155·1413, 1954.
32 Starr, I , and Mayock, R. L · Am J. M. Sc. 210:701, 1945.
33. Starr, I : Pederson, E , and Corbascio, A N · Circulation, 12.588, 1955
34 Makinson, D H Circulation 2·186, 1950.
35. Davis, F W , Jr , and others: Am Heart J. 46:529, 1953.
36 Scarborough, W R , and others: Circulation 4:190, 1951.
37 Henderson, C B · Brit Heart J. 15:278, 1953
38 Mandelbaum, H , and Mandelbaum, R. A : Circulation 5:885, 1952.
39 Dans, F W., Jr , and others: Circulation 7:503, 1953.
40 Henderson, C B . Circulation, 12:858, 1955.
41 Scarborough, W R , and others Am. Heart J. 44·645, 1952.
42 Scarborough, W R , and others· Am Heart J. 45:161, 1953.
43 Starr, I . Am J M Sc 214:233, 1947.
44 Starr, I , and Mayock, R L · Am J. M. Sc. 215·631, 1948.
45 Starr, I Ann Int Med. 37·839, 1952
46 Tannenbaum, O , Vesell, H., and Schack, J. A : Am Heart J. 48:562, 1954

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Roentgenology of the Heart and Great Vessels

Methods of examination made available by roentgenology permit more exact visualization of the size, shape, and position of the heart Knowledge gained by x-ray methods, such as cardiac and vascular pulsations, calcifications in the heart and pericardium, and observations of the intrathoracic vessels, can be acquired only imperfectly and indirectly, if at all, by other diagnostic procedures. Information thus obtained supplements, but never replaces the findings elicited by physical examination.

X-ray studies are of interest in all types of heart disease. In only a minority of cases, however, is the diagnosis dependent solely on roentgenologic findings. Nevertheless, it has been demonstrated repeatedly that x-ray examination is an indispensable aid in answering the basic questions—whether heart disease is present and the nature of the lesion and its severity.

The possibilities of studying the dynamics and size of the heart with accuracy has made the use of x-rays an important procedure in clinical diagnosis as well as a valuable adjunct in medical research.

METHODS OF EXAMINATION

Fluoroscopy: Technically this is the simplest of all x-ray procedures and generally the most available. Fluoroscopy should be used routinely preliminary to other more complicated x-ray studies since it provides promptly a wealth of important information. If fluoroscopy is to be used to its greatest advantage a few elementary but still important technical considerations must be appreciated. It is essential that proper dark adaptation should not be compromised by increasing the intensity of x-rays which should never exceed five milliamperes After preliminary inspection of the thorax, the size of the aperture should be reduced by the shutter, so that only the heart or the area under study is exposed, thereby improving observation by diminishing secondary scattered radiation. This is also an important safety measure, it decreases the dosage to which the patient and examiner is exposed. Persons performing fluoroscopic examinations should be protected with lead gloves and apron. Unfortunately, the cardiologist frequently neglects these protective measures.

In fluoroscopic examination, before centering the attention on the heart

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FIGURE 1 *A*, Posteroanterior projection Right border is formed (from above down) by: superior *vena cava*, ascending aorta, right auricle. *Left border* is formed (from above down) by: arch of aorta (aortic knob), pulmonary artery and left main branch, left auricular append[illegible] oblique [illegible] ventricle below and left atrium above

alone, it is wise to view systematically the thoracic skeleton, the pleura and costophrenic sulci, the position and motion of the diaphragm, the mediastinum, and the pulmonary parenchyma, with particular attention to the peripheral and hilar vessels. After viewing the heart, its size, shape,

and position, in the posterior-anterior position (anterior chest to screen) the patient should be rotated gradually into oblique positions for further study of the cardiac chambers. Figures 1 A-E illustrate the topography of the cardiac silhouette in the frontal and oblique positions. Since better visual accommodation is necessary for the study of cardiac pulsations and the search for intracardiac calcification, these procedures should be carried out last.

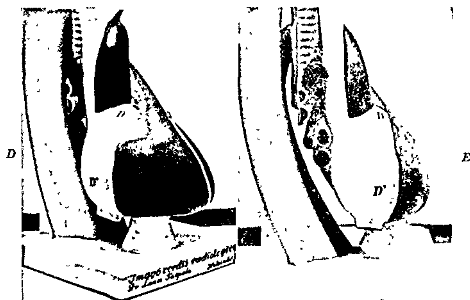


FIGURE 1 *D*, Right anterior oblique projection Anterior border is formed by anterior margin of left ventricle below and above this by infundibular portion of the right ventricle and main pulmonary artery, and aortic arch Posterior border is formed by right atrium (auricle) *E*, Right lateral projection Anterior border is formed by right ventricle, and above by aortic arch Posterior border is formed by left atrium

Fluoroscopy is not well suited for absolute measurement of the heart size since there is considerable magnification of the heart image due to divergence of the x-ray beam resulting from the short tube-screen distance usually employed in fluoroscopic examination. The degree of magnification depends not only on the tube-screen distance, but on the object-screen distance as well. Magnification is, accordingly, greater in subjects with deep chests, in whom the heart contours are further removed from the film, than in slender subjects and children.

The degree of magnification may be calculated from the formula:

$$\frac{\text{object size}}{\text{image size}} = \frac{\text{target-object distance}}{\text{target-film distance}}$$

Magnification can be obviated on fluoroscopy or in roentgenograms by a simple procedure. *A lead scale placed vertically parallel to the cassette* alongside the subject in the plane of the anterior axillary line is magnified exactly in the same proportion as is the heart silhouette. The scale is re-

corded with the heart in the same *exposure* on the fluoroscopic screen or roentgenogram and serves as a reference scale for measurement of the heart size (Fig. 2). This procedure is equally suitable for 35 mm. or 4" x 5" photographs of the fluoroscopic image, a technic which is being increas-



FIGURE 2 A lead scale suspended parallel to the cassette in the plane of the anterior axillary line is recorded on the roentgenogram Projection magnification is of the same order as the heart, and reduction in miniature films is likewise identical The scale recorded in the roentgenogram serves as reference for cardiac measurement

ingly employed, particularly in surveys in the armed forces and industry (Fig. 3).

Miniature roentgenography has proven of considerable value in the detection of heart disease as well as pulmonary disease in screening surveys. The incidence of cardiovascular abnormalities found in routine chest surveys varies from two to six per cent, depending on the age and type of population examined. Over fifty per cent of cardiac abnormalities discovered on routine chest surveys are due to organic heart disease, so that miniature roentgenography is a useful diagnostic procedure.

Orthodiascopy: Projection distortion of the heart in fluoroscopy may be obviated by the orthodiagraphic technic (Fig. 4). Only the central ray of the fluoroscopic beam, whose position is indicated by a small lead marker, is used to trace the outline of the cardiac contour. The screen and patient being fixed, the central ray is moved along the cardiac contour by moving the tube with the left hand, while the right hand follows the lead marker along the heart border recording numerous points at about one centimeter intervals.

The principle and technic of orthodiascopy are quite simple and the method can be applied with an attachment to ordinary fluoroscopic equip-

ment permitting the tube to be moved independently of the screen However, since there is a large subjective element, rigid attention to details is essential for accuracy. It is important that the screen and patient do not move; respiration, however, need not be suspended since the position of the



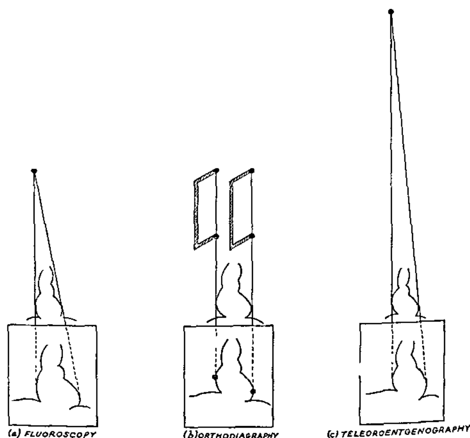
FIGURE 3 Scale with 0 5 cm markings recorded on 14" x 17" roentgenogram as shown in Fig 2 Insert shows fluororoentgenogram of same subject recorded on 35 mm. miniature film at three feet distance Transverse diameter is same with both technics.

heart does not change significantly during ordinary shallow breathing. The points should be traced at about one centimeter intervals, and the diastolic or greatest heart size should be recorded. The lower heart borders should be traced as far as possible below the diaphragm; this is aided by observing the pulsations of the apex through the gastric air bubble The contours of the diaphragm, and other identifying thoracic structures such as the lateral rib margins and clavicles should also be traced as indicated by the central ray marker. Orthodiagraphy does not appear to possess any advantage over the lead scale method described, which may be applied conveniently during fluoroscopy to obtain exact measurements of the cardiac shadow.

Teleoroentgenography: Roentgenography possesses the advantage over fluoroscopic technics of providing an objective and permanent record, not only of the heart, but of the pulmonary fields as well, which are of interest and importance in the diagnosis of heart disease. At two meter (6.5 feet) tube film distance (teleoroentgenography) the magnification of the cardiac image due to divergence of the x-ray beam is reduced to the order of five per cent (Fig. 4), this does not increase appreciably until the tube-film distance becomes less than 150 cm. (5 feet).

Apart from the projection distortion there are numerous other pitfalls in

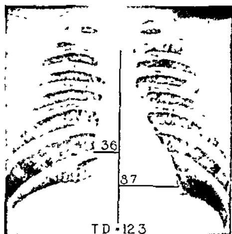
interpretation of roentgenograms of the heart. The size, shape, and position of the heart are influenced by certain physiological variables and technical considerations, which should be appreciated before deciding whether the heart is pathologically enlarged. It is important that the subject be



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marker in its path) (c) Teleoroentgenography. Projection magnification can be reduced to the order of five per cent by removing the tube to two meter target-film distance.

centered properly, which can be recognized in the roentgenogram by an equidistance of the inner borders of the clavicle from the midpoint of the vertebral spine. The tube should be at the level of the third anterior intercostal space. Even slight degrees of rotation may significantly alter the size of the cardiovascular shadow, particularly the aortic arch silhouette. The exposure should be made in the erect or sitting position, and with respiration suspended in ordinary inspiration since extremes of respiration or straining may cause marked variations in the size of the heart (Fig. 5). The size of the cardiac shadow varies considerably depending on the phase of the cardiac cycle in which the exposure is made. When the pulsations are vigorous the transverse diameter of the heart may vary by as much as

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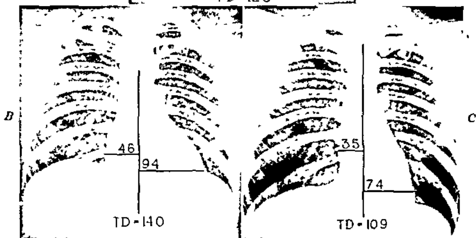


FIGURE 5 *A*, Normal heart, inspiration Respiration may cause marked variation in cardiac dimensions by changing the position of the heart and also because of the influence of intrathoracic pressure on venous return to the heart The heart size is not much affected by ordinary shallow respiration Roentgenograms should be made with respiration suspended in ordinary inspiration *B*, Same subject, expiration During expiration the diaphragm becomes elevated and the heart assumes a transverse position The left ventricular border is displaced to the left and the transverse diameter may be considerably increased *C*, Same subject Valsalva effect [illegible]

are made

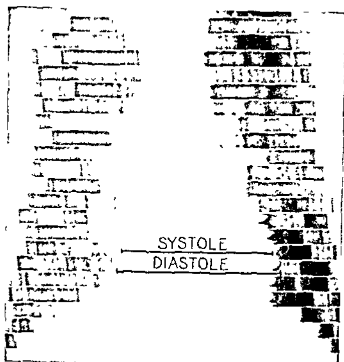


FIGURE 6 Roentgenkymogram, cardiac pulsations. The size of the cardiac shadow varies considerably depending on the phase of the cardiac cycle in which

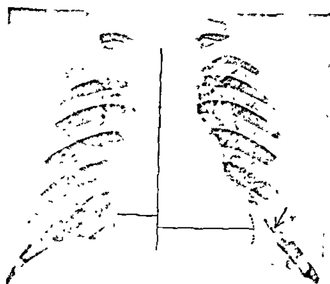


FIGURE 7 Extrapericardial fat pad. Very often, particularly in obese subjects, there is an extrapericardial fat pad which merges with the lower left heart border and may obscure the apex. This shadow must not be included in measuring heart size.

1.5 to 2 centimeters from systole to diastole (Fig. 6). Since diastole is longer than systole at ordinary heart rates, roentgenograms are more often exposed in diastole. It is not true, as is widely supposed, that a full second exposure lasting through a complete cardiac cycle will record the diastolic or largest heart shadow. It has been shown, in fact, that the border of the



FIGURE 8 *A*, Funnel chest The size of the cardiac shadow is usually a reliable index of heart size, but skeletal abnormalities of the thorax may alter the position and shape of the heart, simulating enlargement In this case of funnel chest narrowing of the anteroposterior diameter of the thorax flattens the heart and makes it appear enlarged *B*, Funnel chest, lateral view Lateral view of same case as above shows marked narrowing of the anteroposterior diameter of the chest with depression of the sternum. This case emphasizes that a single view may give an erroneous estimate of heart size

heart in long exposures lasting through the complete cardiac cycle more closely approximates the systolic, or smallest, heart size Prolonged exposures thus serve no advantage and not only give an indistinct cardiac outline but blurred hilar structures as well due to transmitted motion from the cardiac pulsations. Several devices employing pulse waves, heart sounds, and the electrocardiogram have been contrived to permit exposure at selected phases in the cardiac cycle. The technic of roentgenkymography makes it possible to register one or several complete cardiac cycles on a single film and provides a record of the cardiac outline both in systole and diastole.

Several anatomical peculiarities may cause confusion in interpreting the cardiac shadow. The most important is an extrapericardial fat pad which merges with the lower left heart border and which may obscure the apex (Fig. 7). The margin of the fat pad must not be mistaken for the left heart border which may be discerned within the fat pad, particularly if the roentgenogram is made with slightly overpenetrated technic. Skeletal abnormalities of the thorax, such as funnel chest (Fig. 8*a*, *b*) and kyphoscoliosis (Fig. 9), by displacing and distorting the heart occasionally may



FIGURE 9 Kyphoscoliosis, distortion of heart Distortion of the thoracic cage may cause marked displacement of the heart making it difficult to estimate the heart size



FIGURE 10 *A*, Dextroscoliosis The convexity in dorsal scoliosis is most often to the right, and the spine may occasionally be mistaken for the right heart border, making the heart appear enlarged. *B*, Dextroscoliosis of the upper dorsal vertebrae may, as in this case, simulate aneurysmal widening of the aorta

render difficult the accurate determination of the size of the heart. The dextroscoliotic spine may simulate the right heart border or ascending arch of the aorta (Fig. 10), and a diagnosis of cardiac enlargement or dilatation of the aorta may thereby be made erroneously. The size, shape, and particularly position of the heart may be altered in pulmonary diseases such as fibroid phthisis, atelectasis, pneumothorax, etc.; and by diaphragmatic hernia or elevation of the diaphragm as in pregnancy and ascites (Fig. 11).



FIGURE 11. Megacolon The diaphragm is elevated and the heart is displaced to the right Even greater degrees of displacement may be produced by eventration of the diaphragm

Roentgenkymography: Roentgenkymography is an ingenious technic for graphically recording the movements of the heart on a single film. A permanent objective record of the cardiac and vascular pulsations is thereby obtained which permits more detailed and exact analysis of the movements of the heart than is possible on fluoroscopic examination.

The principle of roentgenkymography is illustrated in Fig. 12. In order to record the pulsations of numerous points along the cardiac contour simultaneously a grid with multiple horizontal slits is employed rather than the single slit method, as illustrated in Fig. 13. With the multiple-slit grid the film must be moved only just a little less than the distance between two slits in order to prevent overlapping of the waves of adjacent segments. The type of grid most commonly employed has slits 0.4 mm. wide, spaced at 12 mm. intervals The film is moved downward a little less than 12 mm. during a continuous exposure of one to two seconds, with respiration suspended in the phase of moderate inspiration. Thus, depending on the heart rate and duration of exposure, one to three complete cardiac cycles are generally recorded (Fig. 13). Since the film moves down

during the exposure, the time ordinate is directed upward, *i. e.*, the beginning of exposure is at the lower margin of a segment, the end of exposure above.

While the technic described is the one most generally employed, there are many variations. Thus, the grid may be moved and the film held

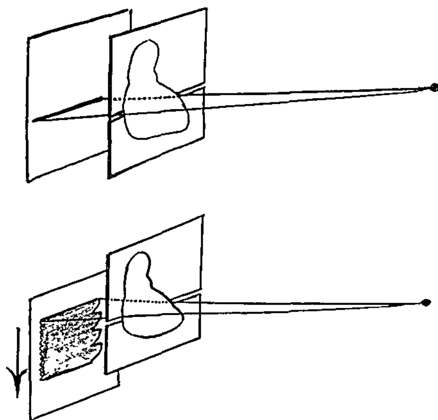


FIGURE 12 Principle of [illegible] x-ray exposure, the pulsations of the two opposite points of the cardiac contour visualized will be recorded on the moving film in the form of waves, the waves being repeated with each cardiac cycle.

stationary during the exposure, instead of moving the film as described above. The type of kymogram obtained with this method is illustrated in Fig. 14. Although the other thoracic structures appear in their normal configuration with this technic, the moving-film kymogram is usually preferable because it more closely portrays the movements of single points along the cardiac contour. Other types of grids have been employed In addition to the movements at the border which are recorded by the kymogram, there are density changes in the heart shadow during the cardiac cycle.

The kymogram of a normal subject is illustrated in Fig. 13. The waves of each chamber are characteristic. The ventricular wave consists funda-

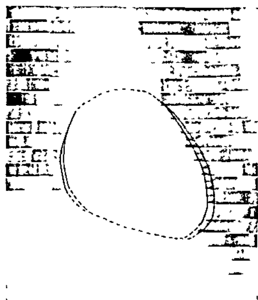


FIGURE 13 Roentgenkymogram of normal subject Outline of heart in systole and diastole

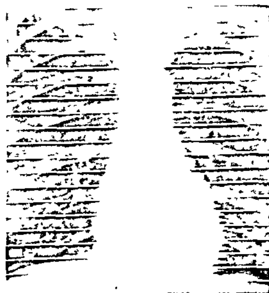


FIGURE 14 Roentgenkymogram with moving grid and stationary film The other thoracic structures appear in their normal relationships, in contrast to their segmented appearance in the moving film kymogram This type of kymogram is not as satisfactory as the moving film kymogram, since it less accurately portrays the movement of single points of the heart

mentally of a slow, bent, outwardly directed limb representing filling, succeeded by a sharp inthrust representing systolic ejection. The peaks of the waves therefore represent maximum diastole, and the troughs represent maximum systole. By connecting the peaks and troughs of adjacent

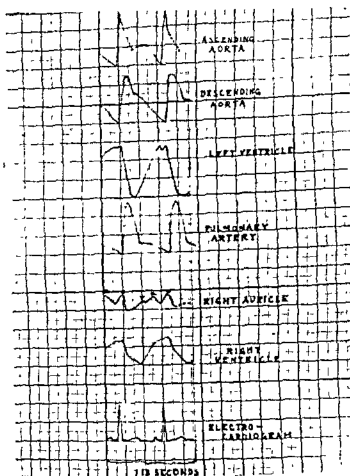


FIGURE 15. Graphic correlation of the kymographic waves of various chambers in a normal subject, with a simultaneously recorded electrocardiogram.

segments one can obtain the outline of the ventricle in systole and in diastole. The aortic wave shows a sharp out-thrust synchronous with ventricular systole, and this is succeeded by a slow recession of the wave during diastole, interrupted by the aortic incisura. The auricular waves consist of multiple small serrations.

All of the segments are comparable in time since they are taken during the same exposure. Time resolution is accurate within 0.03 second. The waves of the different chambers may be graphically correlated on a time axis, and the sequence of events throughout the cardiac cycle can be carefully analyzed. Fig. 15 shows a graphic analysis of the various waves on a time axis, together with a simultaneously recorded electrocardiogram. By correlation with the electrocardiogram and heart sound records, the waves may be assigned to specific events in the cardiac cycle. The phenomena

recorded kymographically are readily susceptible of physiologic interpretation. The ventricular wave corresponds roughly to experimental ventricular volume curves. The waves of the aorta and pulmonary artery are identical with arterial sphygmograms. The auricular waves frequently show three small serrations which correspond to the a, c, and v waves of the jugular pulse.

Roentgenkymography thus provides a direct and convenient method of studying and teaching certain aspects of human cardiac physiology which have hitherto required difficult animal preparations employing the myocardiograph and arterial sphygmograph. Since the outline of the heart is recorded both in systole and in diastole kymography provides the most exact method available for studying the size of the heart The difference in size in systole and diastole provides a measure of the cardiac output, and calculation of the cardiac output by kymograph methods checks closely with the acetylene technic.

The ventricular and vascular pulsations undergo characteristic changes in various cardiac lesions. The practical clinical value of kymography is somewhat limited; it is useful whenever it is desired to study the pulsations of the heart, aorta, and pulmonary artery in greater detail than is possible on fluoroscopic examination. Kymography has been applied to study the movement of other viscera such as the diaphragm, gastrointestinal tract, and ureters.

A modification of the kymograph, the electrokymograph, has been developed by Henny and Boone. The cardiac pulsations are recorded *via* a photo-sensitive tube placed over the heart border during fluoroscopy This technic permits study of the pulsations of segments of the cardiac contour in greater detail than is possible with the roentgenkymogram.

Contrast Angiocardiography: Visualization of the cardiac chambers and the intrathoracic blood vessels can be accomplished by intravenous injection of seventy per cent diodrast according to the technic developed by Robb and Steinberg. With a large 12-gauge needle stopcock unit firmly in place in the median basilic vein and the patient properly positioned, 30 to 50 cc. of seventy per cent diodrast are injected within two seconds or less. The rapid arrival of undiluted dye in the thorax is facilitated by elevating the arm and instructing the subject to inhale deeply at the moment the injection is begun. The first roentgenogram is exposed two seconds later and eight serial roentgenograms are exposed at two second intervals, employing either the rapid film changer technic or multiple exposure fluorographic technic devised by Sussman, Steinberg, and Grishman. When the velocity of blood flow is slowed as in cardiac decompensation, appropriate exposure times may be ascertained by preliminary circulation time tests with decholin or other agents for combined "right and left heart" times, and ether for "right" or CO_2 inhalation for "left" heart times. The left anterior oblique position, except when special information is desired, yields most information, since in this position the individual heart chambers, position of the interventricular septum, and the entire aortic arch are most clearly differentiated. Dilution of the dye in the pulmonary vascular bed is an obstacle to good visualization of the

left heart chambers and aorta, particularly if pulmonary congestion is present. Diodrast has been injected directly into the aorta for improved visualization of the main arterial trunks.

Aortography, although seemingly formidable, has proven a safe and use-



FIGURE 16 Contrast visualization of cardiac chambers (left anterior oblique position) Two seconds after intravenous injection of seventy per cent diodrast and opaque material is seen in the superior vena cava, right auricle, right ventricle, pulmonary artery and its larger branches The left cardiac chambers are not yet visualized

ful technic in study of abnormalities of the aorta and its major branches, *e. g.*, the renal arteries. Various modifications of aortography have been employed including retrograde aortography by passage of a catheter into the proximal aorta from the subclavian or external carotid artery. Diodrast has been instilled directly into the heart by catheter during cardiac catheterization or by direct injection into the cardiac chambers. Among the various applications of contrast angiography cerebral arteriography is probably the most important. This is carried out by injecting opaque media into the carotid artery.

When the multiple exposure technic is employed in angiocardiography the progress of the radiopaque diodrast column can be followed in serial films through the superior vena cava, right atrium and ventricle, pulmonary vessels, left atrium and ventricle, aorta, and even into the innominate, left common carotid, and left subclavian arteries (Figs. 16 and 17). It is evident therefore that contrast angiocardiography provides more exact information concerning the morphology of the heart and intrathoracic blood vessels than is obtainable by any other procedure. This method has contributed much to more precise identification of the cardiovascular structures and the topography of the cardiac silhouette both in normal

subjects and in those with various types of heart disease. It is of clinical value in the differential diagnosis of congenital cardiac lesions, mediastinal tumors and aneurysms, and pericardial effusion.

Many other diagnostic applications of angiocardiography have been



FIGURE 17. Contrast visualization of cardiac chambers (left anterior oblique position). Seven seconds after intravenous injection of seventy per cent diodrast the opaque material is seen in the left ventricle arch of the aorta and brachiocephalic arteries. The diodrast column has passed through the right cardiac chambers and pulmonary artery which are no longer visualized

described, including the demonstration of dissecting aneurysm of the aorta which may be revealed by a double barreled contour. Vascular rings and other arterial and venous anomalies may be demonstrated. Abnormalities in the pulmonary circulation are revealed even more clearly than in the systemic circulation. Angiocardiography has demonstrated an unexpectedly frequent occurrence of aberrant and accessory pulmonary arteries and veins, and has aided in the diagnosis of pulmonary arteriovenous aneurysm and hemangioma.

If a roentgenkymogram in the left anterior oblique position is taken following injection of diodrast interesting physiological information is obtained. This technic has been employed by the authors to analyze the dynamics of the interventricular septum. It is found that the septum is by no means a mere partition between the two ventricles but functions as an integral and important part of the left ventricle. The septum, which moves to the left during systolic contraction, exhibits a large amplitude of pulsation frequently exceeding the pulsations of the lateral wall of the left ventricle. In its movement to the left the septum carries the right heart chambers with it, accounting for the ventricular type of pulsations seen along the right heart border. Roentgenkymography during contrast

visualization yields additional information. The thickness of the ventricular wall can be measured quite accurately, and the extent of systolic emptying of the ventricle can be directly observed. Even in normal individuals an appreciable residue remains in the left ventricle at the end of systole, so that systolic emptying is not complete. Contrast roentgenkymography is of further utility in pericardial effusion. With this technic the heart shadow and its pulsations may be clearly distinguished within the effusion. Whereas the pulsations at the periphery of the effusion are damped the pulsations of the ventricle within the effusion remain of normal amplitude unless tamponade occurs.

The technic of angiocardiography is not free of hazard. Fatalities have been calculated to occur in 0.38 per cent of cases studied, so that a clear cut indication should be present before such study is carried out.

Body Section Roentgenography: The laminographic technic has been applied principally for improved definition of selected regions in pulmonary disease, but may be used to advantage to visualize the aorta to better advantage than is possible in the conventional roentgenogram. Laminography is a useful procedure in demonstrating the presence and extent of calcification of the aortic and mitral valves. This has become a matter of practical importance in the preoperative appraisal of patients subjected to aortic and mitral valvulotomy.

Various other roentgenologic procedures have been applied to study of the heart, among them direct simultaneous serial roentgenography in two planes. This technic has been employed by Swedish radiologists during angiocardiography to provide precise three dimensional analysis of the cardiac chambers

Cardiac Catheterization: A further diagnostic procedure which utilizes roentgenographic technic is venous catheterization of the heart. A radiopaque catheter, after introduction into a vein, is passed into the right heart chambers under fluoroscopic observation. Important information is obtained from the position of the catheter, and from pressure recordings and oxygen saturation of blood samples from the right heart chambers and pulmonary artery. Quantitative determination of blood flow may be carried out using the Fick principle. This method has proven of inestimable value in the differential diagnosis of congenital cardiac lesions and has made possible precise analysis of the pathologic physiology of various types of heart disease. The procedure is a complex one; the method and its applications have been described in detail by Cournand and other investigators Recently catheterization of the left heart has been employed by passing a catheter through a needle inserted into the left atrium *via* the back.

CARDIAC ENLARGEMENT

Cardiac enlargement and hypertrophy are reserve mechanisms whereby the heart is adapted to protracted strain so that it may maintain an adequate circulation. Hypertrophy and dilatation as a rule are closely associated, so that when the heart is enlarged some degree of dilatation of the cardiac chamber is usually present with myocardial hypertrophy. Since oxygen consumption is proportional to diastolic volume the cardiac output

is maintained by the enlarged heart with greater energy expenditure; hence, efficiency is decreased. Cardiac enlargement therefore betokens impaired reserve. Its recognition is a most important sign both in the diagnosis of heart disease and as a prognostic guide.



FIGURE 18. Concentric left ventricular hypertrophy in hypertensive heart disease The left ventricular contour is rounded, i e, increasingly convex, the dimensions of the cardiac shadow are but slightly increased Tortuosity of the aorta is present.

The four cardiac chambers are individual functional units and react independently to the strain imposed by the various lesions Abnormalities in the cardiac configuration should always be considered in terms of the chambers involved. It is more informative to describe the individual chambers specifically than to employ less precise phrases such as enlargement to the left and to the right, or such terms as "mitral" or "aortic" configuration. The shadows of the separate chambers merge imperceptibly in the cardiac shadow, but the contours in frontal and oblique projections permit adequate differentiation and visualization of all the chambers. The topography of the cardiac silhouette in various projections is illustrated in Fig. 1a-e. Three views suffice for study of all the chambers, aorta, and pulmonary vessels. These are the conventional posteroanterior, and the oblique projections; the left anterior oblique, and the right anterior oblique or right lateral position (with the esophagus outlined by barium).

The Left Ventricle: The anterolateral wall of the left ventricle forms practically the entire left heart border in the posteroanterior position; the posterior wall may be studied by rotating the patient into the left anterior oblique position. This chamber is the one most frequently placed strain in the commoner types of heart disease.

The configuration of the enlarged left ventricle varies somewhat de

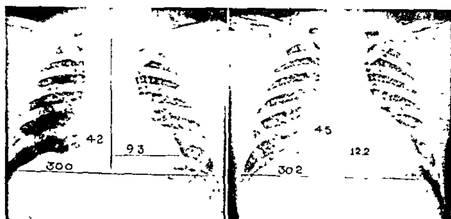
ing on whether hypertrophy or dilatation predominates. In the earlier stages of hypertensive heart disease, for example, there may be considerable myocardial hypertrophy with relatively little dilatation (concentric hypertrophy). Hypertrophy as such is a matter of increase in the thick-



FIGURE 19 Aortic insufficiency Downward enlargement of left ventricle, apex in sixth intercostal space

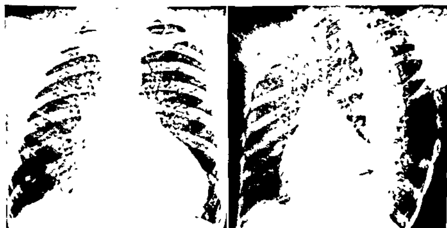
ness of the left ventricle of only a few millimeters and so does not perceptibly alter the dimensions of the cardiac shadow. The shape of the left ventricular border, however, is characteristically altered in concentric hypertrophy, becoming increasingly convex, *i. e.*, more rounded (Fig. 18).

Enlargement of the left ventricle occurs downward, laterally, and posteriorly. Downward enlargement is recognized by elongation of the left ventricular contour, the apex extending to the sixth intercostal space. This type of enlargement is seen particularly in aortic insufficiency where dilatation of the left ventricular cavity predominates, the diastolic volume necessarily being large because of the increased systolic output (Fig. 19). Enlargement of the left ventricle laterally is evident by extension of the left ventricular border outside the midclavicular line (Fig. 20). This criterion is the one regularly employed on physical examination, but can be applied even more accurately in the roentgenogram. Posterior enlargement of the left ventricle is best evaluated on fluoroscopic examination in the left anterior oblique position. On rotation into the left anterior oblique position the posterior surface of the left ventricle clears the anterior border of the spine at an angle not greater than sixty degrees (Fig. 21). When marked enlargement is present the left ventricular border may not clear the spine even on rotation into the full left lateral position. While enlargement laterally, downward, or posteriorly may predominate in slight degrees



A *B*

FIGURE 20 *A*, Hypertensive heart disease, left ventricular hypertrophy, chiefly concentric hypertrophy *B*, Same subject as Fig 20, *A*, ten years later Left ventricular enlargement is more marked Marked enlargement of the heart over a short period of time does not commonly occur Acute dilatation of the heart is rare The right ventricle dilates more rapidly than the left under conditions of acute strain, probably because the myocardium of the right ventricle is thinner than that of the left ventricle



A *B*

FIGURE 21 *A*, Marked left ventricular enlargement downward and laterally [illegible]

is marked, as in this case, the angle of clearance is greatly increased

of enlargement, extension of the left ventricular border in all directions occurs in more advanced stages.

Left ventricular hypertrophy ordinarily is revealed earlier in the electro-

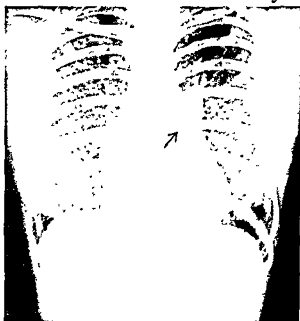


FIGURE 22 Right ventricular enlargement The right ventricle does not contribute to the cardiac contour in the posteroanterior projection (Fig. 1 A). Enlargement is indicated indirectly by upward displacement and rotation of the pulmonary artery filling in the concavity of the cardiac waist The upper of the two curves between the aortic knob and left ventricle is the pulmonary artery, the lower the left auricle The increased prominence of the right heart border is due to displacement of the right auricle by the enlarged right ventricle.

cardiogram than it is by roentgenographic methods. Increased voltage of the QRS complex usually is present before there is a measurable increase in the size of the heart in the roentgenogram.

The Right Ventricle: The right ventricle does not participate in forming the cardiac contour in the posteroanterior projection since it forms the anterior surface of the heart (Fig. 1*a*). Nevertheless, enlargement of this chamber is indicated indirectly in this position. As the right ventricle increases in size it displaces the right auricle to the right causing increased prominence and convexity of the right heart border. Even more characteristic is a straightening and increased prominence of the upper left heart border between the aortic arc and the left ventricular segment (Fig. 22). This results from elevation and rotation of the pulmonary artery by the enlarged outflow tract or infundibular portion of the right ventricle so that its contour becomes more prominent than the normal pulmonary artery curve. The term "prominent pulmonic conus" is commonly employed to describe these changes. Actually, the conus, or infundibular portion of the right ventricle, appears on the upper left heart border only in advanced cases (Fig. 23). When right ventricular hypertrophy is marked with relatively little dilatation, as in congenital cardiac lesions such as tetralogy of Fallot, a characteristic change in the left heart bor-

der is observed. The apex is elevated by the hypertrophied body of the right ventricle (inflow tract) producing a rounding of the lower left contour (*coeur en sabot*) (Fig. 24).



FIGURE 23 Marked right ventricular enlargement When enlargement of the right ventricle is marked the infundibular portion may come to occupy the upper left heart border, as in this case of advanced mitral stenosis



FIGURE 24. Right ventricular enlargement, tetralogy of Fallot. The *coeur-en-sabot* configuration results from hypertrophy of the body of the right ventricle as contrasted with enlargement of the infundibular portion or outflow tract of the right ventricle illustrated in Fig 23 The cardiac apex is elevated, producing the blunted curve of the lower left heart border.



FIGURE 25 Enlargement of the right ventricle, right anterior oblique projection The infundibular portion of the right ventricle is greatly enlarged, bulging forward toward the sternum Note also in this case of mitral stenosis the indentation and backward displacement of the barium-filled esophagus due to mitral valvular disease



FIGURE 26. Right ventricular hypertrophy, left anterior oblique projection. Hypertrophy of the body of the right ventricle (inflow tract) is indicated in this view by an increased forward bulge of the anterior cardiac contour (compare with Fig 1, *B*).

The right ventricle is best studied by examination in oblique views. In the right anterior oblique position a forward bulge of the infundibular portion of the right ventricle (outflow tract) toward the sternum is observed (Fig. 25). A rounding and anterior extension of the lower right

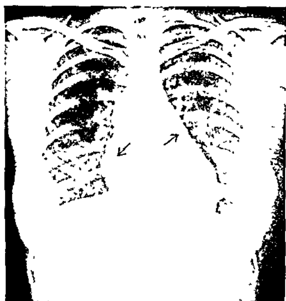


FIGURE 27 Enlargement of the left atrium, posteroanterior projection The left atrium does not contribute to the cardiac silhouette except for a small and incon- [illegible]

displacement of the barium-filled esophagus to the right as seen through the cardiac shadow Oblique views are preferable for detecting early enlargement of the left atrium

ventricular border observed in the left anterior oblique position occurs at a somewhat later stage This is indicative of hypertrophy of the body of the right ventricle (inflow tract) (Fig. 26). Signs of enlargement of the right ventricle both in the electrocardiogram and x-ray are due more to rotation in the position of the heart than to hypertrophy as such. Consequently, it is difficult to distinguish right ventricular hypertrophy from positional changes in the heart either by x-ray methods or with the electrocardiogram (*e. g*, in pulmonary emphysema and fibrosis)

The Left Atrium: The left atrium forms the posterior surface of the heart and does not contribute to the cardiac silhouette in the posteroanterior projection except for a small and variable segment of the left auricular appendage above the left ventricular border. The left atrium enlarges posteriorly and to the right, and only in slight degree to the left. Occasionally the enlarged left auricle projects to the left causing a slight bulge above the left ventricular contour. Ordinarily, however, the filling in and straightening of the "cardiac

waist" above the left ventricle which is characteristically observed in mitral valvular disease (the commonest cause of left atrial enlargement) is due chiefly to associated right ventricular enlargement displacing the pulmonary artery, rather than to left atrial enlargement *per se*. Rarely in cases with marked left atrial enlargement this chamber may project considerably from the upper left heart border (Fig. 28).

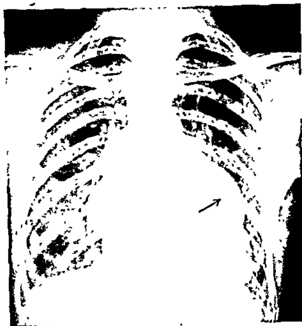


FIGURE 28 Left atrial enlargement to the left. The left atrium enlarges chiefly posteriorly and to the right Infrequently, as in this case, it may enlarge to the left, projecting above the upper left heart border.

A much more frequent finding in the presence of marked left atrial enlargement is extension of the left atrium to the right, projecting beyond the border of the right auricle. A double festoon results, the upper arc being the left atrium, the lower segment the right atrium (Fig. 27). The left atrium may in certain cases with free mitral insufficiency become massively dilated, coming to occupy the lower half of the right thoracic cavity (Fig. 29).

Oblique views are indispensable to establish the presence of lesser degrees of enlargement of the left atrium. In the left anterior oblique position the left atrium forms the upper portion of the posterior cardiac border (Fig. 30). Normally a space of approximately a finger's breadth is present between the upper border of the left atrium and the left main bronchus. As the atrium enlarges this space becomes obliterated (Fig. 31). Further degrees of enlargement elevate and ultimately compress the bronchus (Fig. 32). It must be emphasized that elevation of the left main bronchus is not an early sign of left atrial enlargement. It is preceded by obliteration of the infrabronchial space.

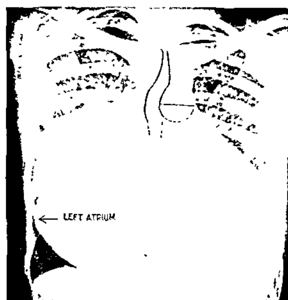


FIGURE 29 Massive enlargement of the left atrium. The left atrium is enormously dilated, occupying the entire right lower thoracic cavity Oblique projections in this case showed backward displacement of the esophagus against the spine and also elevation and compression of the main bronchi and posterior displacement of the trachea. The left ventricle is also greatly enlarged in this case with long-standing free mitral insufficiency. [illegible] of the dilated left

invariably present. A long, loud systolic murmur is heard over the precordium, the diastolic murmur of mitral stenosis may be lacking



FIGURE 30 Left atrium, left anterior oblique projection. Normally, free space is present between the left main bronchus and upper border of the left atrium in the left anterior oblique projection.



space As
al
al

enlargement, such as backward displacement of the esophagus



FIGURE 32 Enlarged left atrium, elevation of left main bronchus, left anterior oblique projection Elevation of the bronchus is not an early sign of left atrium enlargement It is preceded by obliteration of the infrabronchial space



FIGURE 33 Enlarged left atrium, right anterior oblique (or right lateral) pro-

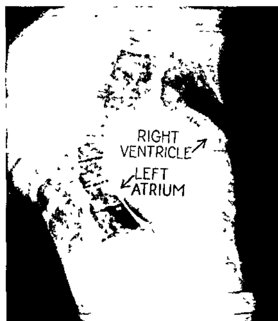


FIGURE 34. Enlarged left atrium, right anterior oblique projection. When enlargement of the left atrium is marked, the esophagus is displaced posteriorly against the anterior border of the spine Note also in this case of mitral valvular disease marked enlargement of the right ventricle is indicated by the forward bulge of the upper anterior heart border



FIGURE 35. Enlargement of the right atrium (tricuspid stenosis and insufficiency, mitral stenosis and insufficiency). Note the sagging lower right heart border extending far to the right. It is obscured somewhat by a right pleural effusion Enlargement of the heart to the right is not specific of right auricular enlargement since it may result from other causes such as pericardial effusion, massive left atrium, and displacement of the right auricle by enlarged right ventricle Elevation of the venous pressure and enlargement of the liver in the presence of a prominent right heart border favor the diagnosis of enlargement of the right auricle.

The right anterior oblique or right lateral position ordinarily gives the earliest indication of left atrial enlargement. The left atrium enlarges posteriorly into the retrocardiac space. This is evident directly on fluoroscopic examination or in the roentgenogram when well marked, but the detection of this change is greatly facilitated by outlining the esophagus with barium. The esophagus pursues a vertical course in the posterior mediastinum directly behind and in apposition with the posterior surface of the heart (left atrium). As the left atrium enlarges the barium-filled esophagus is indented and displaced posteriorly in the retrocardiac space, beneath the impressions of the left main bronchus and the aortic arch (Fig. 33). When marked atrial enlargement is present the esophagus is displaced far backward against the anterior border of the vertebrae (Fig. 34). Minimal left atrial enlargement is best detected by administering a thick barium paste which adheres to the esophageal mucosa, outlining it for some length of time after swallowing It is inadvisable to expose roentgenograms during swallowing of a thin barium mixture such as is used in gastrointestinal study, for the barium bolus can indent the left atrium during deglutition so that lesser degrees of retrodisplacement of the esophagus will escape observation. The esophagus is displaced not only posteriorly but somewhat to the right, which is revealed by rotating the subject into the posteroanterior or anteroposterior position after examination in the right anterior oblique view. Posterior displacement of the esophagus is the earliest and most certain sign of enlargement of the left atrium, and usually antecedes other changes such as obliteration of the infrabronchial space, elevation of the left main bronchus or straightening of the upper left heart border.

Esophagrams made in the recumbent position may reveal indentation and retrodisplacement by the left atrium more distinctly than in the upright position.

Although roentgenologic changes provide a reliable index of left atrial enlargement, occasionally in subjects with mitral stenosis x-ray findings may be entirely negative while the electrocardiogram reveals widening and notching of the P waves indicating left auricular hypertrophy. In young individuals such P wave changes are quite specific of left auricular hypertrophy. The disparity may be due to the presence of auricular hypertrophy without atrial dilatation in such cases.

The Right Atrium: The right atrium (auricular portion) forms the entire right heart border. Enlargement results in extension of the right heart border laterally. Prominence of this contour, however, is not specific since a prominent right heart border may result from enlargement of any of the cardiac chambers, particularly the right ventricle, displacing the right atrium to the right. Enlargement of the right atrium usually occurs as part of generalized cardiac enlargement, almost never as an isolated clinical entity. Enlargement of this chamber is most noteworthy in tricuspid valvular disease (Fig. 35). Marked right auricular enlargement is evident in the left anterior oblique position as a forward bulge of the upper anterior heart border above the right ventricular contour (Fig. 36).

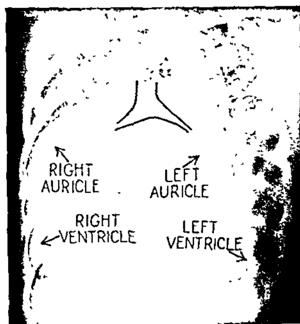


FIGURE 36 Enlargement of the right auricle, left anterior oblique projection When right auricular enlargement is marked it may project above the right ventricular contour in the left anterior oblique projection Note the marked enlargement of all the other heart chambers in this case with advanced rheumatic heart disease

CARDIAC MEASUREMENTS

Several measurements such as those of Vaquez (Fig. 37) and Fray (Fig. 38) have been proposed which purport to serve as criteria for enlargement of the individual heart chambers. The value of such measurements is, at best, limited. Attempts to measure the cardiac chambers separately are necessarily inexact since only one border is visualized, the shadows of the various chambers merging to form the cardiac silhouette. The relation of the heart to adjacent structures, such as the esophagus, bronchi and thoracic parietes, determined by fluoroscopy and teleoroentgenogram study in posteroanterior and oblique positions as already indicated, is of greater value than mensuration in detecting enlargement of the individual chambers.

Measurements are of greater value as an index of generalized enlargement of the heart than in determining the size of the individual chambers. There is a definite field of usefulness for measurement standards in evaluating enlargement of the heart as a whole since very often enlargement does not involve individual chambers distinctly and one can state only that the heart is enlarged. Mensuration is unnecessary when gross enlargement exists, but lesser degrees of enlargement often escape detection on inspection. Conversely, an apparently large cardiac shadow may assume less significance when it is considered in relation to standards of body build. If proper account is taken of the physiological variables which influence the size of the heart, mensuration is a valuable aid in determining whether the heart is enlarged. Measurement is helpful also in comparison

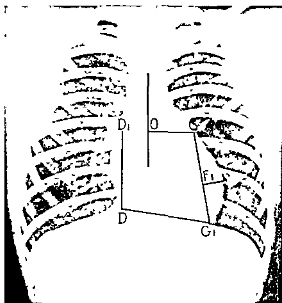


FIGURE 37 Cardiac measurements (Vaquez)

GG_1 left ventricular diameter	maximum	8 5 cm
	minimum	6 7 cm
	average	7 5 cm
F_1 left ventricular curve (index of hypertrophy)	maximum	2 0 cm.
	minimum	0 6 cm
	average	1 3 cm
DG_1 diameter of right ventricle	maximum	14 7 cm.
	minimum	8 5 cm
	average	11 6 cm
DD_1 diameter of right auricle	maximum	7 5 cm
	minimum	3 5 cm
	average	5 0 cm
OG diameter of the left auricle	maximum	5 0 cm
	minimum	3 5 cm
	average	4 2 cm.

Measurements are of greatest value as an index of general and enlargement of the

of changes in heart size in serial examinations in the same subject Another field where measurement has found wide application is in physiological and pharmacological investigations of the heart.

Several physiological factors may influence the size of the heart and these must be recognized and considered in evaluating measurements. Body build has a most important determining influence on the size of the heart. The correlation of heart size with various factors, such as weight, height, surface area, muscular development, thoracic circumference, and other thoracic measurements, etc., has been probed extensi

dependence on weight is somewhat greater than on height but the correlation is improved if both weight and height are considered. A $\frac{\text{weight}}{\text{height}}$ index has been evolved which appears to serve as a satisfactory coefficient



FIGURE 38 Diameters in left anterior oblique position (Fray). In the left anterior oblique position (45°) the left ventricle forms the posterior border. Mensuration in this position has been suggested for detection of right and left ventricular enlargement This is based on diameters drawn to the right and left borders from a point within the cardiac shadow (C) on a perpendicular dropped from the anterior border of the trachea. This is *assumed* to represent the plane of the interventricular septum Normally the "right ventricular diameter" (CR) and the "left ventricular diameter" (CL) are equal, and the transverse diameter of the heart (CR + CL) is fifty per cent or less than the distance from the right anterolateral chest wall to the left costovertebral articulation (AB). Increase in the right or left ventricular diameters beyond twenty-five per cent of the transverse diameter of the chest (AB) supposedly indicates enlargement of the right or left ventricle.

for prediction of normal standards. The influence of sex, and of age in adults, on the size of the heart is relatively small compared with the factors of weight and height, and for practical purposes may be disregarded in prediction standards.

Of the many measurements that have been advocated the best known are the transverse, longitudinal, and broad diameters (Fig. 39). These few simple measurements suffice to determine whether the heart is enlarged. The transverse diameter, and the area of the frontal cardiac silhouette, which may be determined from the long and broad diameters (*v.i.*), are the most thoroughly tried and standardized and among the best of all measurements. In addition, the heart volume, which is of great physiological interest, can be accurately calculated from these diameters.

The simplest, most widely employed, and one of the most useful meas-

urements is the transverse diameter, which is the sum of the greatest extension of the right border to the right, and of the left border to the left, of the midline. The cardiothoracic ratio, which is predicted on the assumption that the transverse diameter should be less than half the transverse

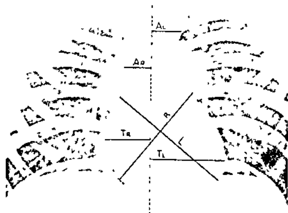


FIGURE 39 Cardiac diameters

Transverse diameter = TR + TL
(sum of maximum projections to right and left heart borders from *midline*)

Long diameter = L
(extends from junction of cardiac silhouette and vascular pedicle on right to apex on left)

Aortic arch diameter = AR + AL
(sum of maximum extensions to right and to left borders of vascular pedicle from midline)

Broad diameter = B
(greatest diameter of cardiac shadow perpendicular to long diameter This is sometimes drawn of the sum of two perpendiculars from the long diameter to the right and to the left heart borders For calculation of the cardiac area in the nomogram, the broad diameter should be drawn in a single line as indicated. When the heart is transversely placed, it may be necessary to extend the lower right heart border in its natural curve to delineate the margin of the broad diameter)

diameter of the chest at the level of the diaphragm, has been widely popularized, but is crude and inexact. The width of the thorax is only a rough index of body stature, and is altered in any given case by respiration, and also in pathologic conditions, such as emphysema Ordinarily the transverse diameter of the heart is considerably less than half the transverse diameter of the chest, so that appreciable enlargement may escape detection if this ratio is employed as an index of the size of the heart. More accurate standards, based on weight and height, have been established both for the orthodiagram and teleoroentgenogram. Teleoroentgenographic

standards are slightly greater than those for the orthodiagram, so that it is not proper to use the orthodiagram values in reading teleoroentgenograms. Because of the increasing employment of the teleoroentgenogram, a new prediction table, based on a study of 1460 teleoroentgenograms of

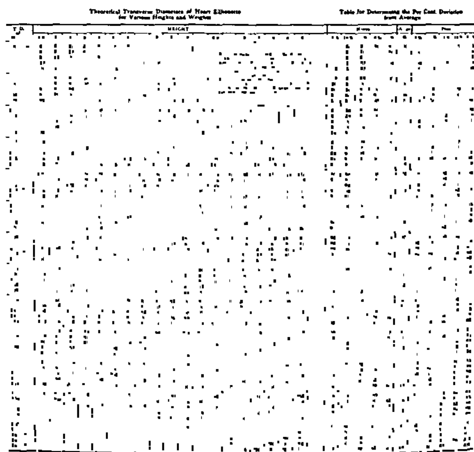


FIGURE 39*A* Teleoroentgenographic standards

normal subjects, has been prepared, and this should be employed, rather than the older orthodiagram standards, when reading teleoroentgenograms (Table 1). A nomogram indicating the predicted transverse diameter from weight and height has been prepared by the authors (Fig. 43).

The actual transverse diameter should not be interpreted too strictly in relation to the predicted value, for there are appreciable physiologic variations in the size of the cardiac shadow in addition to changes due to the phase of the heart cycle and respiration. Diameters which are more than ten per cent above the predicted value should be regarded as abnormal, and the heart may be considered as almost certainly enlarged if the transverse diameter is over fifteen per cent in excess of the predicted diameter, since less than three per cent of normals exceed this limit. An increase in the transverse diameter is most often caused by enlargement of the left ventricle, but enlargement of any of the cardiac chambers, even of the left auricle, when it forms the right border of the heart, can widen the transverse diameter.

Two other diameters, the long and broad diameters, are well known, although these are somewhat less valuable individually than the transverse diameter. The long diameter extends from the junction of the cardiac and vascular silhouette on the upper part of the right border of the heart

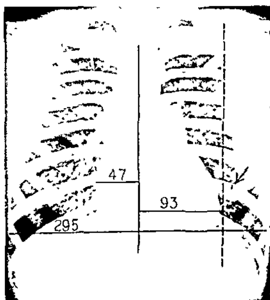


FIGURE 40 Cardiothoracic ratio Predicted transverse diameter in this case of aortic insufficiency is 12 3 cm., actual transverse diameter is 14 0 cm, fifteen per cent above the predicted The cardithoracic ratio

$$\frac{\text{(transverse diameter of heart)}}{\text{(internal t. d of chest)}}$$ is normal (forty-seven per cent)

This ratio, which regards that the t d of the heart should be less than half the internal t d of the chest, is the poorest of all measurements and should be discarded. Note that the left heart border lies within the midclavicular line despite the definite enlargement, and that the midclavicular and nipple line (indicated by arrow pointing to lead marker) do not coincide

obliquely downward to the apex on the left. This diameter, which is approximately ten per cent greater than the transverse diameter, is increased chiefly as a result of left ventricular enlargement. The broad diameter is the greatest diameter perpendicular to the long diameter. The broad diameter is often drawn as the sum of two perpendiculars from the long diameter to the lower right and upper left heart borders, but properly it is the greatest single diameter from upper left to lower right heart border perpendicular to the long diameter. If the heart is placed transversely, it may be necessary to extend the lower part of the right border slightly below the diaphragm in its natural curve in order to delineate the limit of the broad diameter. The broad diameter averages about fifteen per cent less than the transverse diameter.

The long and broad diameters are of interest, not so much by themselves, but for their product, which is an expression of the two-dimensional size of the cardiac shadow. The product of these two diameters, which has been termed the heart rectangle, has been recommended as an index of the size

of the heart in relation to the product of the height and width of the thorax (Fig. 41). This ratio is expressed as: $\frac{\text{rectangle of heart } (L \times B)}{\text{rectangle of lung } (H \times W)}$

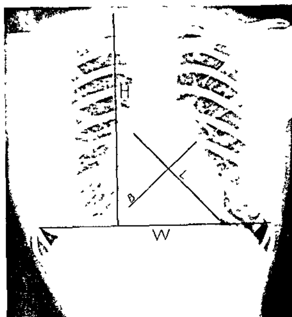


FIGURE 41 Heart-lung rectangle. The ratio of the product of the long and broad diameters to the product of the width and height of the thorax has been recommended as an index of heart size This ratio is expressed as

$$\frac{\text{Rectangle of heart } (L \times B)}{\text{Rectangle of lung } (H \times W)} \begin{cases} \text{asthenic build} & 20 \text{ per cent} \\ \text{medium build} & 22 \text{ per cent} \\ \text{sthenic build} & 26 \text{ per cent} \\ \text{average} & 23 \text{ per cent} \end{cases}$$

If the ratio is over twenty-eight per cent the heart is considered enlarged

Normally the ratio averages twenty-three per cent; it varies from twenty per cent in subjects of asthenic habitus to twenty-six per cent in those of stocky build. The heart is considered enlarged if the ratio exceeds twenty-eight per cent. Although standards based on thoracic configuration are less accurate than those predicted from weight and height, this ratio is less open to criticism than the cardiothoracic ratio, in which only the width of the chest is considered. When the weight and height are not available, as is frequently the case in hospital studies, the ratio, $\frac{\text{heart rectangle}}{\text{lung rectangle}}$, is a suitable method for evaluating the size of the heart. An even simpler criterion, which is very satisfactory, is the relation of the left border of the heart to a line dropped from the midpoint of the clavicle Extension of the left border outside the left midclavicular line is usually indicative of left ventricular enlargement, and does not commonly reveal changes in the other cardiac chambers, but it is the left ventricle which is most frequently enlarged in heart disease. This criterion has long been employed in physical examination, but serves equally well in roentgenologic study.

Frontal Area: The area of the frontal cardiac silhouette in relation to standards based on weight and height has been widely recommended as an excellent criterion of the size of the heart. In order to ascertain the area of the frontal silhouette, the upper and lower limits of the heart shadow

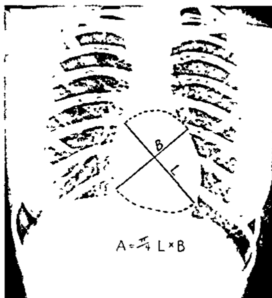


FIGURE 42. Frontal cardiac area The area of the frontal cardiac silhouette in

planimeter or by counting squares within the area on cross section paper In orthodiagraphy observation of the pulsations helps in outlining the contours In the teleoroentgenogram, however, the error in completing the upper and lower borders is much greater and for this reason frontal area determinations have not [illegible] yields [illegible] in the [illegible] ulated [illegible] $= \pi/4$ [illegible] of this formula yields values which correspond very closely to the actual areas deter- [illegible]

(Fig. 43) permits the frontal area to be read directly without calculation from the long and broad diameters Predicted values for the frontal area from weight and height are shown in the same nomogram

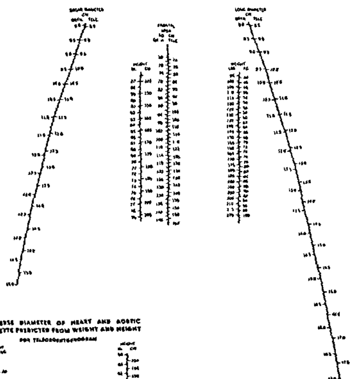
must be completed by arbitrary and imaginary lines, and this requires considerable experience to attain duplicable results. The area is measured by means of a planimeter, or by counting squares within the area on cross-section paper. In orthodiagraphic examination, observation of the pulsations helps in outlining the upper and lower limits of the heart contour. In the teleoroentgenogram, however, the error in completing the upper

and lower borders is much greater, and, for this reason, satisfactory frontal area measurements have not been obtained from the teleoroentgenogram, although this method yields excellent results in orthodiagraphy in the hands of those who are well trained in the technic. Inasmuch as the cardiac shadow is ellipsoid in shape, its area may be calculated from the product of its axial long and broad diameters (area of ellipse $= \frac{\pi}{4}$ long $\times$ broad diameters) (Fig. 42). Calculation of the cardiac area by means of the formula, $\frac{\pi}{4}$ long $\times$ broad diameters, yields values which correspond very closely to the actual area, as measured by planimetry (within three per cent). This product may, therefore, be used to estimate the cardiac area in lieu of planimetry. This is of particular advantage in the teleoroentgenogram because the long and broad diameters can be measured accurately, whereas the planimetric estimation of the cardiac area is less accurate. The product, ⅔ long $\times$ transverse diameters, approximates the cardiac area, but is less satisfactory than the product of long and broad diameters, for the mean deviation from actual areas, as ascertained planimetrically in 134 orthodiagrams, was found to be seven per cent, whereas with the long and broad diameter product the mean deviation in the same group of 134 cases was less than three per cent. The actual cardiac area should not exceed ten per cent over the predicted value, and, if it does, the heart may be considered enlarged. A nomogram for prediction of the cardiac area from weight and height, and actual area as calculated from the long and broad diameters, is illustrated in Fig. 43. The nomogram permits the frontal area to be read directly without calculation from the long and broad diameter measurements. Predicted values for the frontal area based on weight and height are indicated in the same nomogram chart on another scale.

Heart Volume: The cardiac area is of great interest in another regard, in that is bears a close relation to the heart volume; the latter may be calculated from the cardiac area. In an extensive study on sixty-two cadavers, the area of the frontal cardiac silhouette was found to bear a close relation to the heart volume, and the formula $V = 0.53A^{1.5}$ was proposed (where $V =$ heart volume, $A =$ area). More recently a modification of this formula, $V = 0.63A^{1.45}$ has been recommended; this yields values six per cent less than the older formula in the ordinary range of frontal area, varying from 90 to 130 sq. cm. Another formula for estimating heart volume from the frontal area is $V = 0.36$ long $\times$ broad $\times$ transverse diameters This is a modification of the Kahlstorf formula, which has been widely recommended, but which requires study in the lateral as well as the frontal position. In 104 cases, chiefly normal subjects, the mean heart volume, as calculated by this formula, was 680 cc., whereas the mean heart volume as calculated by the Bardeen formula was 687 cc. The average deviation of these two formulas was 41 cc. Several other methods which take into account measurements in lateral or oblique positions, in addition to the frontal views, have been suggested. When the heart volume is estimated from teleoroentgenograms, it is necessary first to correct the

diameters for magnification (Fig. 43) before multiplying them to obtain the volume.

Although estimation of the heart volume is of great theoretical interest, the practical applicability is limited, particularly when study in more than



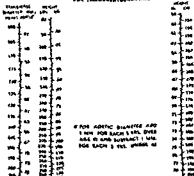


FIGURE 43. Nomograms for area and transverse diameter of frontal heart silhouette

one position is required. Apart from considerable variations in normal subjects, the volume varies from twenty-five to thirty per cent between systole and diastole, and the phase of the cycle must, therefore, be known. The volume during systole and diastole can best be estimated by means

of roentgenkymograms. The size of the heart in systole is more constant than the diastolic heart size which is varied readily by many physiological factors which alter filling and stroke output. The systolic heart volume averages 320 cc./m.[2] body surface with a standard deviation of almost 50 cc. The systolic heart area averages 60 sq. cm./m.[2] body surface with standard deviation of 6 sq. cm.

The difference between the diastolic and systolic volumes, as measured kymographically, may be employed to estimate cardiac output. The accuracy of the kymographic method for determining stroke volume compares favorably with the standard acetylene technic. Since oxygen consumption is directly proportional to fiber length, or diastolic volume, the cardiac output is maintained by the dilated or hypertrophied heart with greater energy expenditure; hence, efficiency is decreased. The ratio, $\frac{\text{diastolic heart volume}}{\text{stroke volume}}$, which ordinarily varies from seven to ten is a direct expression of the efficiency and functional state of the heart in accordance with Starling's Law. Both these functions can be determined from a single roentgenkymogram. This ratio is of greater significance than the heart volume or stroke volume alone, and any considerable increase betokens impaired cardiac reserve.

Size of the Heart in Children: The contours of the individual chambers of the heart and the great vessels forming the vascular pedicle are not so clearly defined in the cardiac silhouette of children as in adults. The wide range of the normal cardiac configuration in infancy and early childhood dictates reserve in making a roentgenologic diagnosis of heart disease unless there is definite evidence of enlargement. The thymus gland frequently casts a distinct shadow which overlies and merges with the upper cardiac shadow, and which may simulate cardiac enlargement or vascular anomalies. Further difficulty in interpreting roentgenograms of the heart in infants and young children arises from frequent inability to control such factors as phase of respiration, precise positioning (unless strapped), and crying which may alter the size of the heart due to changes in intrathoracic pressure.

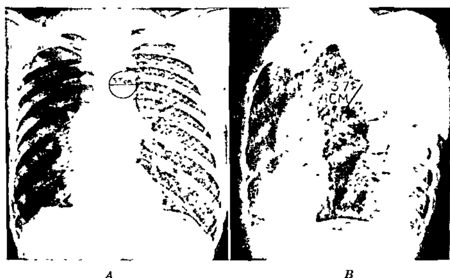
The criteria for enlargement of the separate cardiac chambers are the same in children as in adults. Of particular importance are (1) fluoroscopic observation of the angle of clearance of the left ventricle in the left anterior oblique position for the detection of left ventricular enlargement, (2) backward displacement of the esophagus in the right anterior oblique position to demonstrate left atrial enlargement, and (3) prominence of the conus (outflow tract) of the right ventricle in the right anterior oblique position as a sign of right ventricular enlargement.

The most useful measurements in children, as in adults, are the area of the frontal cardiac silhouette and the transverse diameter. Prediction standards have been established based on study of an age group between 2.9 and 18.8 years. The formula for predicted area (sq. cm.) is: 0.160 Height (cm.) + 1.045 Weight (kg.) + 13.7. Where the actual area is calculated from roentgenograms, employing the formula area equals $\frac{\Pi}{4}$

long $\times$ broad diameters, correction of the diameters for projection magnification should first be made. The prediction formula for transvere diameter (cm.) is: 0.0637 Weight (kg.) + 7.5.

MEASUREMENT OF THE AORTA

Roentgenologic examination of the heart should invariably include observation of the aorta, for abnormalities such as widening, tortuosity, and calcification occur frequently in heart disease, particularly in hypertensive and arteriosclerotic heart disease and in syphilis. Measurement of



A *B*

FIGURE 44 *A*, Measurement of the aorta Widening of the frontal aortic arch silhouette may result from dilatation or tortuosity of the aorta The true diameter of the aorta at the level of the transverse arch may be ascertained by completing the arc of which the aortic knob is a segment when the knob is distinct or with [illegible] es around the [illegible] ie level of the [illegible] cm. in adults, [illegible] r oblique posi- [illegible] ig arch is evi- [illegible] *B*, Study of [illegible] is seen in this case that the apparent aneurysmal widening of the aorta suggested by the posteroanterior view is really due more to tortuosity although there is some widening of the ascending arch The diameter of the transverse arch can be measured directly in the left anterior oblique position if contrast is good, and the diameter here is identical with that determined in the posteroanterior position by the segmental method. *The caliber of the aorta, pulmonary artery and its branches are best studied by the visualization with diodrast*

the true caliber of the aorta is difficult because both contours are not visualized in the frontal position. The left border of the descending aortic arch is visualized in the frontal roentgenogram, and, if the esophagus is filled with barium, the right border of the aorta is indicated by the aortic indentation of the esophagus; therefore, the diameter at this level of the aorta can be ascertained by subtracting 2 mm. representing the thickness of the esophageal

wall (Kreuzfuchs' method [Fig. 29]). The method is not dependable when the aorta is tortuous and the aortic knob projects to the left. Where a portion of the aortic knob is distinct, as is usually the case in adults, the true diameter of the aorta at this level may be ascertained simply by completing the circle, of which the aortic knob is an arc, by means of a compass (Fig. 44*A*). The caliber of the aorta determined by this simple procedure checks exactly with the diameter obtained by visualization of the aorta in the left anterior oblique position and with the Kreuzfuchs' method. The diameter of the transverse arch of the aorta can frequently be measured directly in the left anterior oblique position, particularly when some degree of emphysema is present to aid contrast, or when overpenetration technic is employed (Fig. 44*B*). The diameter of the aorta at this level averages 3.0 to 3.5 cm. in adults, varying from 2 to 4 cm. depending on body build and age.

These methods indicate the size of the transverse and descending aortic arch, but it is the ascending aorta which is most often enlarged in disease. The first portion of the ascending aorta is buried in the cardiac shadow, and cannot be studied by any means except contrast visualization with diodrast. The diameter of the ascending aorta just above the aortic valve normally is 1.25 greater than the diameter of the transverse arch at the level of the aortic knob. The ratio does not hold in pathological states since the ascending aorta usually becomes dilated to a much greater degree than the transverse of descending arch. Enlargement of the ascending aorta is evidenced by prominence of the right border of the vascular pedicle and by a forward bulge of the anterior border of the aorta above the cardiac shadow as observed in the left anterior oblique views (Fig. 45).

The right border of the vascular pedicle is formed by the superior vena cava in the majority of young subjects; in later life it is more frequently formed by the right border of the ascending aorta. An increase in the transverse diameter of the vascular pedicle in the frontal roentgenogram does not specifically indicate enlargement of the aorta, for this may result from tortuosity alone; however, this measurement is useful in that it does distinguish between a normal and abnormal aorta (Fig. 39). In a recent study, it was found that the transverse aortic diameter in normal subjects is closely related to weight and height. The table established for predicting the transverse diameter of the heart from weight and height may be employed equally well for the aortic arch diameter (Fig. 43). A correction for age is necessary; 1 mm. is added for each three years over the age of forty-three, and subtracted for each three years under the age of forty-three. Deviations from the predicted value up to ten per cent are within allowable normal limits, but deviations in excess of this are infrequently seen, and the aorta may be considered as almost certainly abnormal if the diameter exceeds fifteen per cent above the predicted value, for ninety-two per cent of normal subjects fall within this range. The transverse diameter of the aortic arch is a simple and valuable standard for measurement of the aorta. It is important that the roentgenogram be made with the subject properly centered, for even slight rotation into oblique position markedly alters the aortic arch transverse diameter. If the diameter

is found to exceed normal values, further study in the left anterior oblique position is indicated, for the aortic arch is best visualized in this view.

THE PULMONARY VESSELS

Pulmonary Arteries: The pulmonary artery contour is visible in the posteroanterior position; more completely, in the slight right anterior



FIGURE 45 Dilatation of ascending arch of aorta, left anterior oblique position (syphilitic aortitis) The aorta bulges forward above the cardiac shadow

oblique projection. The curve of the pulmonic artery lies in the "cardiac waist" between the arc of the descending aortic arch and the upper left ventricular border. It is usually inconspicuous in adults but is more prominent where the heart is vertically placed, particularly in children and adolescents. Prominence of the pulmonary artery contour does not necessarily denote dilatation. In cases with no evidence of heart disease, prominence of the pulmonary artery may be caused by traction upward toward the aortic arch by the obliterated ductus arteriosus. More often, it is due to *upward and lateral displacement by the right ventricle and is, therefore,* an indirect sign of right ventricular enlargement. Dilatation of the pulmonary artery, such as occurs in pulmonic hypertension (cor pulmonale) and in certain types of congenital heart disease (particularly patent interatrial septum and, to a lesser degree, patent ductus arteriosus), is usually accompanied by associated widening of the branches of the main pulmonary artery. The left main pulmonary artery with its larger subdivisions comprises the bulk of the left hilar shadows. Occasionally when enlarged it may be seen as a small hump above the curve of the main pulmonary artery. The right pulmonary artery divides as it courses to the right behind the heart so that the right hilus is composed of secondary branches of the right pulmonary artery. The left pulmonary artery is best visualized

in the left anterior oblique position extending to the left in the aortic window beneath the arch of the aorta. Exceptionally, when dilatation of the pulmonary arteries is marked the caliber of the left pulmonary artery may be as great as or even exceed that of the arch of the aorta. The right pulmonary artery is visualized with difficulty; it is best studied in the right anterior oblique position. Although the right pulmonary artery is not in direct contact with the esophagus it may when considerably dilated produce backward displacement of the esophagus below the aortic impression by displacing the left main bronchus posteriorly. Where it is desired to study the pulmonary arterial tree in detail, contrast angiocardiography employing diodrast is the technic of choice, since the entire pulmonary vascular system is visualized in the finest detail with this method.

The Pulmonary Veins. *Pulmonary Congestion:* The pulmonary veins collect toward the hilar regions to enter the left atrium on the posterior surface of the heart. In the normal subject the pulmonary veins are relatively poorly defined, and the hilar vascular shadows are chiefly arterial. When pulmonary congestion occurs, as in mitral stenosis or left ventricular failure, the engorged pulmonary veins cast more distinct shadows in the roentgenogram. The hilar regions become increasingly dense and the vascular markings in the peripheral lung fields, particularly the lower right pulmonary field, become more numerous. Definite roentgenographic evidence of pulmonary congestion is present frequently where no rales are heard on auscultation of the basal lung fields.

The roentgenographic appearance varies depending on whether the pulmonary congestion is chronic or acute. In chronic pulmonary congestion the base of the lungs is predominantly involved and small aggregates of venous congestion are seen which collect toward the lower right hilar region (Fig. 46). The appearance may simulate bronchiectasis and pulmonary fibrosis which also predominantly involve the lower lung fields, but differentiation is usually possible in that the increased basal markings in chronic bronchitis and bronchiectasis are usually more linear and more clearly outlined than in pulmonary congestion. Some degree of pulmonary fibrosis may occur in pulmonary stasis of long standing producing a fine leafy or lace-like appearance of the parenchyma in the peripheral lung fields.

Acute pulmonary congestion is characterized by changes in the central lung fields as well as, or even to a greater degree than, the basal regions (Fig. 47). The vascular markings, although increased, are very poorly defined so that there is a more or less homogeneous clouding of the hilar regions. The blurring of the vascular markings is due in large part to associated alveolar edema resulting from increased pressure in the pulmonary capillaries. This picture is carried to an extreme in acute pulmonary edema which is characterized by a homogeneous clouding of the pulmonary fields, most marked in the hilar regions fading toward the periphery. Occasionally, particularly in the intense type of pulmonary edema which may occur in uremia, the shadows produced by pulmonary edema may be so large and dense that they may simulate consolidation or neoplasm (Fig. 48).

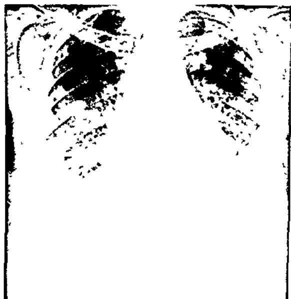


FIGURE 46 Chronic pulmonary congestion Congestive changes are present in both lower lung fields, particularly on the right side Bilateral pleural effusion On the right the pleural effusion extends up into the fissure between the right upper and right middle lobes

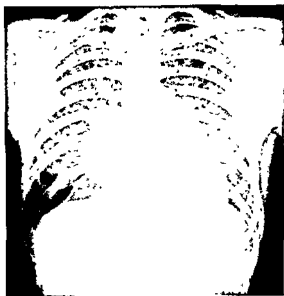


FIGURE 47 Acute pulmonary congestion (Acute heart failure) In contrast to the basal changes in chronic pulmonary congestion, the congestive changes here are most striking in the hilar regions and central lung fields

Pleural Effusion: The parietal pleural veins drain into the vena cava system, while the visceral pleural veins are drained by the pulmonary veins. Consequently, pleural effusion occurs in systemic venous congestion, in right sided failure, as well as in pulmonary congestion (left sided



FIGURE 48 Acute pulmonary congestion, uremia A distinct extreme type of pulmonary congestion is occasionally observed in acute cardiac failure associated with uremia There is intense clouding of the pulmonary fields, chiefly in the central regions with large aggregates which may resemble pulmonary consolidation. The changes are due not only to venous congestion, but also to increased capillary permeability with alveolar edema

failure). The effusion is rarely massive except where associated contributory factors such as low serum protein play a part. More often the effusion is on the right than on the left side. The effusion appears first in the right costophrenic sulcus and extends up laterally and in the interlobar pleura between the right upper and right middle lobes (Fig. 46). Thickening of the interlobar pleura may remain after resorption of the effusion and occasionally serves as a clue to the previous existence of pleural effusion and cardiac decompensation. Pleural thickening can be differentiated from pleural effusion by fluoroscopic observation or with the roentgenkymogram. When fluid is present in the pleural cavity a wave-like motion is observed due to a transmitted impulse with each heart beat. This does not occur with pleural fibrosis.

Pulmonary Infarct: Infarction in the lung is a common complication in heart disease, particularly in the presence of pulmonary congestion. Most frequently the infarct is situated in the lower peripheral lung fields in the subpleural zone. Although a typical triangular lesion with convexity toward the heart is often described more frequently than not the roentgenological findings are atypical or entirely lacking. Unless the infarct is

extensive, such changes as may occur are apt to be masked by associated pulmonary congestion or pleural effusion. Negative roentgenological findings therefore do not exclude the diagnosis of pulmonary infarct when this condition is suggested by such clinical signs as chest pain and hemoptysis.

Pulmonary Embolism: Occasionally a diagnosis of pulmonary embolism is possible from roentgenologic findings such as an amputated hilar shadow and localized emphysema and increased translucency in the portion of the lung where the vascular supply is occluded. Such changes, which are by no means frequent, are masked until the acute inflammatory and atelectatic reactions following pulmonary embolism subside. They may be demonstrated more clearly by fluoroscopy than in roentgenograms. Direct demonstration of pulmonary artery obstruction has been accomplished with the technic of angiocardiography.

SPECIFIC TYPES OF HEART DISEASE

Rheumatic Heart Disease: Enlargement of the heart does not commonly occur in acute rheumatic fever. When present it is usually related to severe carditis, unless there has been pre-existing valvular disease from previous attacks of rheumatic fever. Progressive enlargement over a period of several months is a sign of continuing rheumatic activity and is of serious prognostic import. In such cases there is a high mortality rate and a high incidence of chronic invalidism The size of the heart does not change rapidly even in severe carditis. Marked variations in the size of the cardiac shadow over a short interval are observed in cases with pericardial effusion. Pericarditis occurs relatively infrequently in rheumatic fever. In a series of 100 cases of rheumatic fever studied roentgenographically, pericarditis was encountered in eight per cent; in another series of equal number it was not observed at all.

Valvular deformities develop slowly following rheumatic fever and in time compensatory enlargement of the chambers placed under strain results. Both aortic stenosis and aortic insufficiency cause left ventricular enlargement, but the character of enlargement differs somewhat in these two lesions.

Aortic stenosis causes marked hypertrophy of the left ventricle with relatively little dilatation until more advanced stages. The concentric type of hypertrophy is indicated by a rounding, *i. e.*, increased convexity of the left ventricle. The dimensions of the left ventricle are increased in all directions (Fig 49). Cardiovascular dynamics are not altered unless there is a marked degree of aortic stenosis. In advanced cases the classic *pulsus tardus parvus* may be seen in the roentgenkymogram as a delayed filling of the aorta.

Calcification of the aortic valve occurs commonly in aortic stenosis of long standing. Because of its frequent occurrence late in life some have considered it to be an arteriosclerotic lesion but careful histological studies and history of previous rheumatic infection in a large percentage of cases indicate that most, if not all cases of calcification of the aortic valve, just as calcified mitral valves, are on the basis of antecedent rheumatic valvu-

litis. Calcification of the aortic and mitral valves are best detected on fluoroscopic examination. Proper accommodation is necessary and a small shutter must be employed, preferably with a Lysholm or Potter-Bucky grid to reduce scattered radiation. The valves are centrally placed in



FIGURE 49 Aortic stenosis. Note marked hypertrophy of left ventricle indicated by accentuated left ventricular curve.

the cardiac shadow and are best observed in the slight right anterior oblique position (fifteen to twenty degrees). The aortic valve lies somewhat above and anterior to the mitral valve. Differentiation is easier in the left anterior oblique position, the aortic valve lying in the middle third of the cardiac shadow while the mitral valve is in the posterior third. The large amplitude of motion of the irregularly shaped valvular opacity is of great aid in the fluoroscopic diagnosis of valvular calcification. Valvular calcification may be revealed in the roentgenogram in the slight right anterior oblique position employing overpenetration technic and a grid. It is important not to confuse valvular calcification with calcification of the mitral ring which is of no consequence. This appears as a dense annular shadow in contrast to the smaller and less regular shape of calcified valves.

In aortic insufficiency the regurgitation may be as great at forty to fifty per cent of the output so that a greatly increased systolic ejection is required to maintain a normal minute volume to the tissues. Consequently, the diastolic volume is greatly increased. Enlargement in aortic insufficiency is chiefly a dilatation of the left ventricular cavity; hypertrophy is less marked than in aortic stenosis (Fig. 50, 51). The left ventricular contour is elongated, the apex extending downward to the sixth interspace. Enlargement laterally and posteriorly occurs in more advanced stages. Since in the early stages enlargement is chiefly downward the transverse

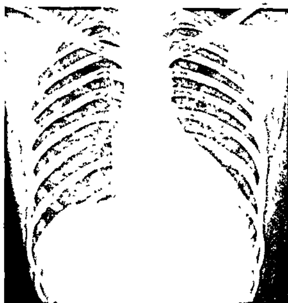


FIGURE 50 Aortic insufficiency, advanced Note marked downward enlargement of the left ventricle due to dilatation of the left ventricular cavity This contrasts with the hypertrophy observed in Fig 49



FIGURE 51 Combined aortic insufficiency and aortic stenosis There is marked hypertrophy and dilatation of the left ventricle

diameter and relation of the apex to the midclavicular line, therefore, are inadequate to detect early enlargement in aortic insufficiency, the cardiac area being more valuable in this lesion. The characteristic elongation of the left ventricular contour (Fig. 19) occasionally leads to the diagnosis



FIGURE 52 Roentgenkymogram in aorti ... pulsations in the aorta with collapse early ... similarly are of large amplitude, indicati ... refilling of the ventricle at the onset of ... aorta Large ventricular type pulsations are present on the right heart border This is due to traction on the right side of the heart during systole by the hypertrophied ventricular septum

of aortic insufficiency which is unsuspected clinically, for the soft high pitched murmur of early aortic insufficiency is the most readily overlooked of all cardiac murmurs. Slight dynamic dilatation of the aorta is frequently observed in aortic insufficiency. The cardiac and vascular pulsations in aortic insufficiency are very characteristic. The pulsations of the left ventricle are greatly increased in amplitude. In addition, the right heart border exhibits large ventricular type pulsations. This is to be ... erventricular septum which draws ... e left during systolic contraction. ... increased in amplitude commen- ... There is a rapid collapse early in diastole due to regurgitation back into the ventricle. This is indicated in the left ventricular wave in the roentgenkymogram by a rapid refilling of

the ventricle at the onset of diastole Fluoroscopically the large ventricular pulsations and oppositely directed movements of the descending aorta are seen as a rocking or see-saw motion of the left border of the cardiovascular shadow (Fig. 52).

Mitral insufficiency and stenosis most frequently are combined to some degree, although either lesion, particularly mitral insufficiency, may exist independently. Both lesions regularly produce enlargement of the left atrium. While slight left atrial enlargement may occur in generalized cardiac enlargement of whatever etiology distinct enlargement of this chamber as revealed by backward displacement of the esophagus is practically pathognomonic of mitral valvular disease (Fig. 33, 34). In cases with marked generalized enlargement of the heart where the left ventricle extends posteriorly slight backward displacement of the esophagus may be observed. The shallow curve of the esophagus in such cases however is differentiated from the higher placed and localized backward displacement of the esophagus in mitral valvular disease The esophageal sign is important confirmatory evidence of mitral disease where the clinical differentiation of an organic *versus* a functional apical murmur is in question. It helps, too, to establish whether an apical diastolic murmur in the presence of aortic insufficiency is an Austin Flint murmur or is due to mitral stenosis.

Right ventricular and ultimately right auricular enlargement occur in mitral valvular disease due to strain on the right ventricle produced by pulmonic hypertension. The association of left auricular and right ventricular enlargement produces the characteristic "mitral configuration" of the cardiac silhouette, with straightened upper left heart border and accentuated right cardiac contour (Fig. 22). While the configuration may be suggestive of mitral disease it is preferable to avoid such terms and to describe anatomical changes in terms of the various chambers involved.

Enlargement of the left ventricle does not occur in uncomplicated mitral stenosis. In fact, the left ventricle tends to be unusually small and is overshadowed by the enlarged right ventricle, which in advanced stages of mitral valvular disease may come to occupy a considerable portion of the upper left heart border (Fig 23). The small left ventricle and hypoplastic aorta so frequently observed in mitral stenosis are due to a decreased cardiac output caused by obstruction of blood flow into the left ventricle through the narrowed mitral valve. In mitral insufficiency, on the other hand, the left ventricle is not small and may be considerably enlarged. The enlargement is due to increased work of the left ventricle since a portion of the systolic ejection regurgitates into the left atrium. Systolic filling of the left atrium due to regurgitation from the left ventricle in mitral insufficiency may be observed in the roentgenkymogram in cases where the left atrium occupies the right heart border. Since the ejection of the left ventricle is increased, the pulsations are of large amplitude and there is a rapid refilling of the ventricle at the onset of diastole from the distended left atrium. Conversely, the left ventricular pulsations are of reduced amplitude in mitral stenosis, reflecting the diminished output. When mitral stenosis is advanced the left ventricle may be observed to fill very slowly in the roentgenkymogram.

Careful roentgenologic study in mitral valvular disease has become a matter of great practical importance since the advent of commissurotomy. Study of the morphology and pulsatile phenomena of the individual chambers helps greatly to decide whether the mitral valvular lesion is predomi-



FIGURE 53 Roentgenkymogram illustrating systolic distention of enlarged left atrium appearing on the right heart border in case with free mitral insufficiency. There is rapid refilling of the left atrium at the onset of diastole.

nantly one of stenosis or if mitral insufficiency is present in significant degree. Left auricular pulsations may be revealed more clearly if the esophagus is first outlined with barium before obtaining a roentgenkymographic or electrokymographic record of left auricular pulsations. Angiocardiography may be useful in indicating the degree of mitral stenosis. When mitral stenosis is marked, with delayed filling of the left ventricle, there is prolonged retention of diodrast in the left atrium which accordingly is visualized for a longer period than normally.

In certain cases with a longstanding free mitral insufficiency, marked enlargement of the left ventricle and tremendous dilatation of the left atrium occur. The left atrium displaces the esophagus posteriorly against the spine, elevates and compresses the main bronchi and extends far to the right, coming to form not only the entire right heart border, but in extreme cases occupying the entire lower thoracic cavity (Fig. 29). This lesion constitutes a unique cardiac syndrome. Despite the remarkable enlargement of the heart, which exceeds that seen in any other condition, there is frequently a surprising freedom from symptoms of impaired cardiac reserve, and individuals with this lesion may continue for years with relatively little limitation of activity. The freedom from pulmonary congestion may be due to the enormously dilated left atrium acting as a reservoir

tween the heart and lungs. This lesion develops most frequently in sub-:ts in the third and fourth decade with a longstanding history of rheumatic art disease. Auricular fibrillation invariably is present. Occasionally a arked systolic heave may be palpated over the right lower anterior chest le to systolic distention of the enlarged atrium resulting from free mitral gurgitation. The systolic distention of the left atrium can be observed *roentgenkymograms which also show large amplitude of the left ventric-*ar contractions with very rapid filling in early diastole from the dis-nded left atrium (Fig. 53).

Tricuspid valvular disease is found with considerable frequency at post-ortem examination in cases with rheumatic heart disease, but only rely is the lesion sufficiently marked as to be of clinical importance. icuspid insufficiency is much more common than stenosis Enlargement the right atrium and right ventricle is observed in the roentgenogram, though there is usually some enlargement of the left atrium and ventricle well due to associated mitral valvular disease (Fig. 35). Freedom from ılmonary congestion is noteworthy, particularly in tricuspid stenosis, d in this lesion enlargement of the right atrium is very striking while e right ventricle is relatively normal in size. Prominence of the superior na cava forming the right border of the vascular pedicle is seen in both ions due to systemic venous congestion

Hypertensive Heart Disease: Hypertension is not synonymous with pertensive heart disease. Elevation of the blood pressure considerably in cess of normal limits may be present for many years, particularly in omen, before evidence of hypertrophy or other cardiovascular changes come manifest. *The degree of enlargement and sclerotic changes in the* rta as observed in the roentgenogram are important prognostic guides. the earlier stages the dimensions of the cardiac shadow may not be rceptibly increased but concentric hypertrophy may be suggested by an creased convexity of the left ventricular border (Fig. 18) Not infre-ently in the earlier stages characteristic electrocardiographic changes dicating left ventricular hypertrophy may be present while the roentgen-ram appears quite normal With increasing duration of hypertension, ogressive left ventricular enlargement outward, downward, and poste-orly occurs With the development of heart failure the other cardiac *ambers become enlarged and pulmonary congestion may be seen* (Fig.).

Abnormalities in the aorta are present as frequently as enlargement of e cardiac shadow, and definite arteriosclerotic changes may be present the absence of any evidence of left ventricular enlargement. Elonga-on and concomitant tortuosity of the aortic arch are characteristic find-gs (Fig. 55). These changes are evidenced by (*a*) increased length from e junction of the heart and vascular pedicle on the right to the aortic ıob on the left, (*b*) prominence of the curve of the ascending aortic arch,) increased prominence and lateral extension of the aortic knob, (*d*) con-*xity of the descending aortic arch, which is normally inconspicuous.* In e left anterior oblique position these changes appear as an uncoiling of e aortic arch (Fig. 47). The elongation of the aortic arch may cai

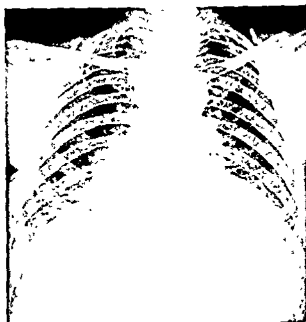


FIGURE 54 Advanced hypertensive heart disease, marked left ventricular enlargement, tortuosity and moderate dilatation of aorta. Congestive changes both in hilar regions and right lower lung field

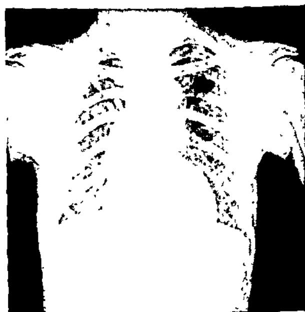


FIGURE 55. Hypertensive heart disease, arteriosclerosis of the aorta The increased width of the vascular pedicle is due to tortuosity of the aorta chiefly, rather than dilatation Other frequently observed changes are elongation of the aorta and calcification most frequently pre [illegible] in the region of the knob tend to be sma [illegible] as often as left ventricular hypertrophy [illegible] with cardiac enlargement. These roentgenologic signs are an important [illegible] nostic guide since they indicate a long-standing background of hypertension.

bowing of the brachiocephalic vessels on the right producing a shadow in the upper right mediastinum which may simulate an aneurysm (Fig. 56). When tortuosity is marked the vascular pedicle in the posteroanterior position may be greatly widened (Fig. 44). The actual caliber of the



FIGURE 56 Elongation of the aorta Bowing of the innominate artery When the aorta becomes elongated the distance from the origin of the innominate artery to the insertion of the internal carotid artery in the cranium is shortened Bowing of the brachiocephalic arteries on the right results It may cast a shadow in the upper right mediastinum simulating an aneurysm This is evident on physical examination as an increased pulsation in the right supraclavicular region

aorta, however, is not as a rule measurably increased, except for moderate dilatation of the ascending aortic arch. Occasionally diffuse dilatation of the entire aortic arch is present. Calcification is very commonly observed in the form of a semilunar plaque in the aortic knob (Fig. 57).

A rare complication of aortic atherosclerosis, usually on the basis of hypertension, is dissecting aneurysm. This usually begins as a transverse tear in the ascending arch of the aorta and blood extends in the aortic arch between the layers of the media. Diffuse widening of the aortic arch shadow is observed. If previous roentgenograms are available for comparison, a marked increase in the width of the vascular pedicle is a helpful diagnostic feature. There is no characteristic roentgenologic picture, although a double barreled shadow may be revealed during diodrast angiography. Extravasation of blood into the pericardium, pleura, or mediastinum may occur which may be detected on x-ray examination. The applicability of roentgenologic study in this condition is somewhat limited. Examination must be confined to the bedside, for such patients are usually gravely ill and sudden death is common.

Arteriosclerotic Heart Disease: Changes in the aorta identical with

those seen in hypertensive heart disease occur in arteriosclerotic heart disease. Calcification of the coronary arteries is rarely found even when over-penetration and short exposure technic are employed.

Demonstration of arterial calcification is the only direct sign of arterio-



FIGURE 57 Calcification of entire aortic arch including aortic valve, left anterior oblique projection Calcification of the aorta is most commonly observed in the region of the aortic knob Calcification of the entire aorta, as in this case, is unusual

sclerosis This may be revealed roentgenographically with surprising frequency in individuals above fifty in the abdominal aorta and iliac vessels. In a series of 320 cases studied by the authors, calcification of the abdominal aorta was found more than five times as frequently as calcification of the aortic knob. Age, diabetes, and hypertension markedly increased the incidence of arterial calcification.

The heart does not enlarge as a rule in acute coronary occlusion or following recovery from infarction except where there has been antecedent hypertension. A relatively small percentage of cases develop progressive cardiac decompensation following coronary artery occlusion and in such instances moderate generalized enlargement may occur. Not infrequently, however, despite definite impairment of the cardiac reserve, and roentgenographic evidence of pulmonary congestion, the heart may be relatively normal in size. In many cases with coronary artery disease the left ventricular contour loses its normal curve and becomes flattened giving a sagging appearance (Fig. 58). This sign, however, is not regularly present, and is at best only suggestive of myocardial disease. Ventricular aneurysm gives a distinctive appearance, and is not infrequently disclosed on roentgenologic study where it is unsuspected clinically. Ventricular aneurysm occurs chiefly following extensive infarction of the anterior wall of the



FIGURE 58 Arteriosclerotic heart disease The heart is not regularly enlarged in coronary artery disease even in the presence of congestive heart failure, as this case illustrates *Sagging of the left ventricular contour may suggest myocardial disease.*

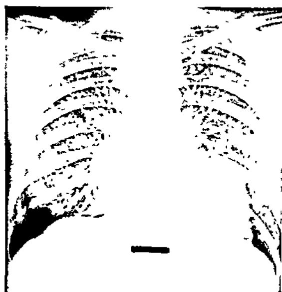


FIGURE 59 Aneurysm of the left ventricle following coronary artery occlusion The aneurysmal sac bulges from the upper left heart border Calcification is occasionally seen More commonly ventricular aneurysm is situated in the region of the apex and cannot be clearly differentiated, so that it may escape detection Subjects with ventricular aneurysm fare surprisingly well clinically Death is usually due *to recurrent coronary occlusion, almost never to rupture of the aneurysm.*

left ventricle, particularly in cases with a deep Q_1, and deep S_2, S_3 type of electrocardiogram. When the aneurysm is located above the apical region an irregularity in the left ventricular border or even a well marked bulge may be observed (Fig. 59). More frequently the aneurysm is situated in the apical region, where it may merge imperceptibly with the left ventricular contour and so is distinguished with some difficulty. Rotation into a very slight right anterior oblique position may bring the aneurysm into better view. Less commonly, ventricular aneurysm may develop following extensive posterior wall infarction and is best revealed by examination in the left anterior oblique position. Calcification of a mural thrombus on the endocardial surface of a ventricular aneurysm or old infarct may be demonstrated occasionally on roentgenographic examination.

Despite the frequency of pericarditis accompanying acute myocardial infarction, pericardial effusion is most rare. The authors have seen one such case during anticoagulant therapy where hemorrhage occurred into the pericardial cavity.

The cardiac pulsations are of greater interest in myocardial infarction than structural changes from a roentgenologic viewpoint. Following coronary occlusion, particularly anterior wall infarction, abnormalities in left ventricular contraction can be observed fluoroscopically or recorded graphically with the roentgenkymograph in a majority of cases

Proper accommodation is essential for fluoroscopic study of the cardiac movements. After inspection of the size, shape, and position of the heart and great vessels the size of the fluoroscopic screen is reduced so that it includes only the left border of the heart. The time relationship of the pulsations is established by comparing the movements of the left ventricle with those of the aorta and pulmonary artery. Normally, the arterial pulsations are opposite in phase to those of the ventricle; the aorta expands while the ventricle contracts, and there is an inthrust of the entire left ventricular border, together with elevation of the apex and diaphragmatic surface of the heart (Fig. 60). The medial movement of the upper part of the left ventricular border may slightly precede the inthrust of the apical region. Following examination in the posteroanterior position, the subject is rotated by degrees into the left anterior oblique position, and the movements of the lateral and posterior walls of the left ventricle are studied successively.

The contractile movements of the heart are observed at the end of a moderately deep inspiration. In addition to immobilizing the diaphragm, this procedure slows the heart rate, and thus facilitates the examination, for a rapid heart rate makes it difficult to visualize the ventricular movements in detail. The patient is instructed not to strain, for this, by increasing intrathoracic pressure, may decrease the venous return to the heart and thereby reduce ventricular ejection and pulsation.

Several maneuvers may be employed when the details of the cardiac movements are not very clear. It is occasionally helpful to magnify the movements by drawing the screen away from the patient, particularly when the pulsations are of small amplitude. The presence of apical peri-

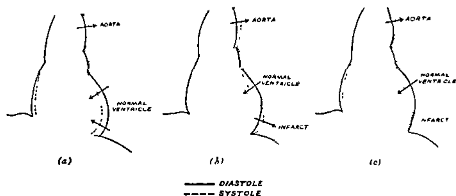


FIGURE 60 (*a*) Normal contraction Entire left ventricle contracts during systole There is an inthrust of the ventricle synchronous with the expansion of the aorta and pulmonary artery (*b*) Reversal of pulsation in cardiac infarction While the upper normal portion of the left ventricle contracts (inthrust), the diseased lower apical muscle is passively expanding during systole (outthrust) (*c*) Absence of pulsation in myocardial disease While the upper normal portion contracts (inthrust), no movement is seen in the affected lower half

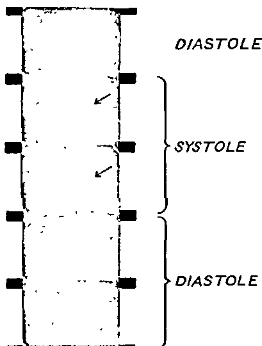


FIGURE 61 Systolic expansion of left ventricle in cardiac infarction. This motion picture strip recorded from a fluoroscopic screen shows systolic expansion of the midregion of the left ventricle in case with anterior wall infarction

cardial fat may obscure contraction and give the impression of diminution or absence of pulsation; one must therefore look within the fat pad to observe the ventricular movements. Since the study of ventricular pulsation is concerned even more with uniformity of contraction along the left

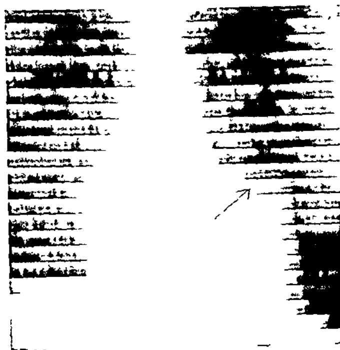


FIGURE 62. Roentgenkymogram illustrating systolic expansion of ventricular aneurysm The ventricular aneurysm is distended at the same time as the aorta at the beginning of systolic contraction. (Same case as in Fig. 59)

ventricular border than with the amplitude of contraction, orientation as to time of contraction is of utmost importance. This may be attained by auscultation; a Bowles diaphragm is held to the patient's chest in the fourth intercostal space. Normally, the inthrust of the ventricle is synchronous with the first heart sound. When the heart rate is rapid, temporary slowing may be induced by pressure on the carotid sinus; this increases the magnitude of ventricular contraction and facilitates the examination.

Reversal of pulsation is the most common and definite abnormality in ventricular contraction associated with myocardial infarction. It is recognized by a loss of uniformity of contraction along the left ventricular border; as the normal portion of the ventricle contracts synchronously with the expansion of the great vessels during systole, the weakened myocardium at the site of the infarct is seen to expand passively as a result of the sudden rise in intraventricular tension (Figs. 60 and 61). This abnormality frequently appears as a wavelike movement along the border of the left ventricle. Similar observations may be made in cases of ventricular aneurysm (Fig. 62). Frequently, reversal of pulsation is complete; occasionally it is incomplete, and appears only as a localized lag of systolic

inthrust, or as a double systolic pulsation. Localized diminution or complete absence of pulsation may also be observed (Fig. 60), but these changes are less definite and significant than systolic expansion. The abnormalities in contraction are commonest over the lower left ventricular

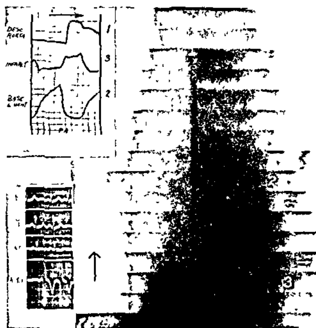


FIGURE 63 Roentgenkymogram in cardiac infarction There is loss of uniformity of left ventricular pulsations While the upper portion of the left ventricular contour contracts normally in systole the lower infarcted region exhibits reversal of pulsation, i e, systolic expansion The electrocardiogram in this subject with an anginal syndrome showed no evidence of myocardial disease The [illegible] the [illegible] e of [illegible] Pre- [illegible] hod, i e, inverted complexes are normal)

border, particularly in the apical and supra-apical regions. Less often the changes are limited to the midregion and upper section of the left ventricular border. These abnormalities in pulsation are observed more frequently and with greater certainty in the posteroanterior than in the left anterior oblique view; rarely, they are limited to the latter position.

Similar abnormalities in left ventricular pulsation are revealed with more certainty by kymographic examination which has the advantage of providing an objective graphic record. The kymogram is of value in evaluating the extent of infarction following recovery from acute coronary occlusion. Prognosis is better in cases with normal left ventricular contraction than in those where a considerable segment of the left ventricular contour exhibits abnormal pulsation, suggesting widespread myocardial involvement. Not infrequently the kymogram may be of value in establishing the

existence of previous infarction in cases where the history is atypical or where the electrocardiogram has returned to normal (Fig. 63).

Luetic Heart Disease: Enlargement of the heart in luetic heart disease is practically always due to aortic insufficiency. Initially the left ventricle is enlarged, the configuration resembling that seen in rheumatic aortic insufficiency. When cardiac decompensation ensues the other chambers are enlarged and pulmonary congestion may be observed. Roentgenologic examination is of value in differentiating an Austin Flint murmur such as occasionally occurs in aortic insufficiency from mitral stenosis Normal size of the left atrium, as indicated by absence of posterior displacement of the barium-outlined esophagus, favors a diagnosis of Austin Flint murmur rather than mitral stenosis.

Cardiovascular lues is essentially a disease of the aorta and x-ray study is a most important diagnostic aid in establishing the presence of aortitis. Widening of the aorta, particularly the ascending aortic arch, characteristically occurs. The true caliber of the ascending aorta cannot be determined by any method other than contrast visualization which is a highly technical procedure not generally available. The simplest and best standard for measurement of the aorta is the Sheridan index of the transverse diameter of the frontal aortic arch silhouette. This measurement does not distinguish widening from tortuosity of the aorta since both may widen the vascular pedicle. Increase in the diameter beyond allowable limits does however indicate that the aorta is abnormal. If the roentgenogram is exposed with proper positioning and the subject is under forty and does not have hypertension it may be safely assumed that an increased frontal aortic arch diameter indicates true dilatation (Fig. 64). Where widening of the aorta is suspected, further study in the left anterior oblique position is indicated. Dilatation of the ascending aorta is revealed by a forward bulge of the ascending aortic arch shadow above the cardiac silhouette (Fig. 45).

Beyond the age of forty, and particularly in the presence of hypertension, it becomes difficult to state definitely that dilatation of the aorta is due to specific aortitis. Dilatation of the ascending aortic arch results from arteriosclerosis of the aorta as well as from aortitis, and a clinical differentiation is equally difficult since systolic murmurs at the aortic area are heard in both conditions. Study of the aortic knob (transverse arch) is of some help in the differential diagnosis. Luetic aortitis frequently causes widening of the transverse as well as the ascending aortic arch. The diameter of the aorta at the level of the knob may be measured, as previously described, by completing the circle of which the aortic knob forms an arc. Hypertension and arteriosclerosis increase the prominence of the aortic knob due to tortuosity of the aorta but do not as a rule cause widening of the aorta except in the ascending portion of the arch.

Aneurysms may assume the most diverse shapes depending on the portion of the aorta from which they originate, their size and whether they are solitary or multiple. In general, there are two types of aneurysm, fusiform aneurysm with diffuse widening of the entire aortic arch, best studied in the left anterior oblique position (Fig. 65), and saccular aneurysms (Fig. 66-73). Saccular aneurysms may arise from any portion of

the thoracic aorta. Preliminary fluoroscopic examination will reveal the position best suited for roentgenographic demonstration of the aneurysm Pressure effects on adjacent organs such as displacement of trachea, bronchi, esophagus, pulmonary vessels, and even the heart may be noted in roentgeno-



FIGURE 64 Luetic aortitis Dilatation of the ascending arch of the aorta The heart is not enlarged unless aortic insufficiency occurs

grams, as well as such changes as erosion of the anterior surface of the dorsal vertebrae, and pulmonary changes secondary to bronchial obstruction.

Findings of some value in differentiating aortic aneurysms from mediastinal tumors include the following.

(*a*) Evidence of widening of the aorta in addition to the aneurysmal mass

(*b*) Calcification within the aneurysm, which may appear as laminated striations. This is present in a minority of cases

(*c*) Regular concentric outline and homogenous density in contrast to the frequent irregularity of mediastinal tumors

(*d*) Expansile pulsations Pulsations are best studied by means of the roentgenkymogram. Movements at the border of the mass do not definitely establish a diagnosis of aneurysm, for a mediastinal tumor may exhibit transmitted pulsations if in close proximity to the aorta. Cyclic density changes synchronous with movements at the border, however, denote an expansile rather than transmitted pulsation and favor the diagnosis of aneurysm Absence of pulsation does not exclude the presence of aneurysm, for not infrequently a sacculated aneurysm may be filled with clotted blood and may fail to pulsate. Pulsation has been observed to disappear following wiring due to clotting within the aneurysm

(*e*) Displacement of mediastinal structures particularly the esophagus and trachea is much more striking in aneurysm of the transverse arch than in mediastinal tumor

(*f*) Therapeutic radiation does not decrease the size of an aneurysm whereas some types of mediastinal tumors respond to radiation with decrease in size.

(*g*) Contrast visualization of the aorta with diodrast is a valuable diagnostic procedure in cases where the aforementioned signs are inconclusive.

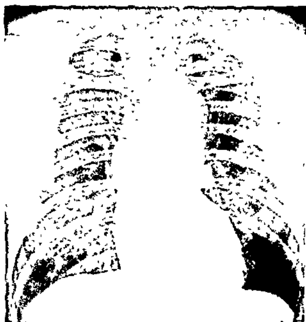


FIGURE 65 Luetic aortitis. Fusiform aneurysmal dilatation of the arch of the aorta

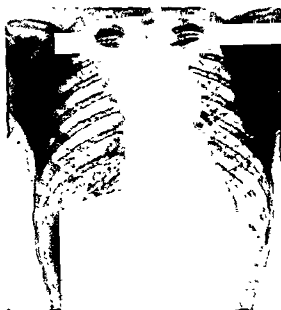


FIGURE 66. Aneurysm of the ascending arch of the aorta and innominate artery



FIGURE 67 Roentgenkymogram of same case as in Fig 66 There are no pulsations at the border of the aneurysm. Autopsy showed a saccular aneurysm filled with clot



FIGURE 68 Aneurysm of the transverse arch of the aorta

Congenital Heart Disease: The advent of surgical corrective measures has made precision in the diagnosis of congenital heart lesions imperative. Roentgenologic examination is an important diagnostic aid. Changes characteristic of the various lesions are produced by strain on the particular chambers involved in the altered circulatory dynamics and by gross malformations and transposition of the heart and/or great vessels. The technics of contrast visualization of the heart chambers and particularly



FIGURE 69 Roentgenkymogram of same case as Fig 68; exhibits expansile aortic pulsations



FIGURE 70 Aneurysm of descending arch of aorta.

venous catheterization of the heart, both of which utilize roentgenologic methods, have contributed immeasurably to the precise diagnosis of congenital heart disease. These specialized technics are not generally available; fortunately most congenital lesions of the heart produce fairly characteristic changes in ordinary roentgenograms, so that in conjunction with the clinical picture adequate diagnosis is usually possible.



FIGURE 71 Multiple saccular aneurysm of aorta Laminated calcification is present

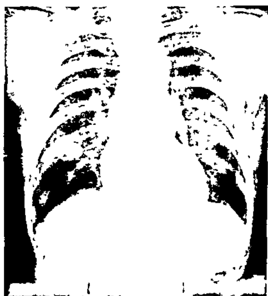


FIGURE 72 Aneurysm of descending arch of the aorta, posteroanterior projection.

Roentgenologic changes, as well as murmurs and electrocardiographic findings, are much less specific in infants and very young children with congenital heart lesions than in older children and adults. The changes characteristically observed in the various conditions described below may not be present in the first few years of life.



FIGURE 73 Same case as in Fig 72, left lateral projection A large aneurysmal mass is present which has caused erosion of the anterior surface of several dorsal vertebrae

Interatrial Septal Defect: This is an acyanotic lesion and compatible with relative longevity. Slight cyanosis may be present if the left to right shunt is reversed due to an increased pressure in the right atrium as occurs when heart failure supervenes, or following exercise and the valsalva experiment which abruptly increase the venous return. Frequently this lesion escapes detection until middle life since clinical findings are minimal, a systolic murmur frequently being present over the pulmonic area with an accentuated pulmonic second sound. Patent interatrial septum is not to be confused with patent foramen ovale which is a very small communication between the auricles, very commonly found at autopsy, of no clinical consequence. The left to right shunt in the atria causes marked dilatation of the right auricle and ventricle and particularly of the pulmonary artery and its branches. The pulmonary artery is tremendously dilated and its caliber exceeds that of the aorta which tends to be small (Fig. 74, 75). Dilatation of the secondary pulmonary arteries in the hilar regions is similarly marked producing dense circumscribed shadows. Fluoroscopically and in the roentgenkymogram the pulsations of the pulmonary vessels are seen to be of large amplitude reflecting a widened pulse pressure in the pulmonary circuit. The roentgenologic picture of patent interatrial septum is perhaps the most characteristic of any congenital lesion.

Angiocardiographic examination employing diodrast may reveal simultaneous filling of right and left atria and prolonged visualization of the right atrium due to recirculation from the left to right atrium through the interatrial septal defect. The tremendous dilatation of the pulmonary vessels is clearly visualized with this method.

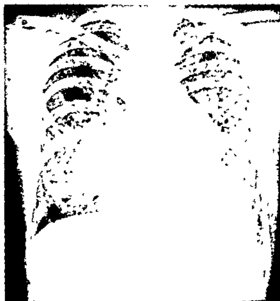


FIGURE 74 Interatrial septal defect. Marked dilatation of the pulmonary artery and its branches with aneurysmal dilatation of right pulmonary artery The heart is considerably enlarged.



FIGURE 75. Right anterior oblique projection of same case as Fig 74 illustrates aneurysm of right pulmonary artery

Idiopathic Dilatation of the Pulmonary Artery: Aneurysmal dilatation of the pulmonary artery due to congenital hypoplasia without any other lesions is occasionally observed. The heart is not enlarged, and even if pulmonic insufficiency is present the degree of right ventricular enlargement is much less than in patent interatrial septum. This condition does not cause symptoms as a rule and may be discovered inadvertently during x-ray examination of the chest or at autopsy (Fig. 76). A systolic murmur may be heard over the pulmonic area.



FIGURE 76 Aneurysm of pulmonary artery. The aneurysm of the pulmonary artery was detected ir [illegible] grams showed large p [illegible] definitely indicative o [illegible] pulmonary artery with aneurysm, etiology unexplained Aneurysm of the pulmonary artery is rarely on a luetic basis.

Aneurysms of the pulmonary artery on a mycotic and luetic basis have been described but such lesions are quite rare. Secondary dilatation of the pulmonary artery and its branches, of considerable degree, may occur due to pulmonary hypertension resulting from mitral stenosis or obstructive lesions in the pulmonary bed (*i. e.*, factors causing cor pulmonale such as pulmonary fibrosis).

Arteriovenous aneurysm of a pulmonary artery is a rare lesion which produces a characteristic syndrome of cyanosis, polycythemia, clubbing, and a nodular shadow in the lung fields, usually in the lower lobes The heart may be enlarged

Patent Ductus Arteriosus: While it might be expected *a priori* that the pulmonary artery would be greatly dilated in patent ductus due to shunting of blood from the aorta, actually the degree of dilatation of the pulmonary artery is almost never as great as that observed in patent interatrial

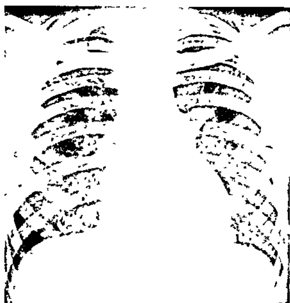


FIGURE 77. *Patent ductus arteriosus* The *pulmonary artery is prominent, moderate cardiac enlargement is present*



FIGURE 78. Roentgenkymogram of case illustrated in Fig 77 *The pulsations of the pulmonary artery are large, exceeding those of the aorta in amplitude*

septum. In a majority of cases moderate dilatation of the main pulmonary artery is observed (Fig. 77); the secondary branches are slightly to moderately increased in size. Occasionally the pulmonary artery may appear normal. The prominence of the pulmonary artery in patent ductus arteriosus is due in some cases not to dilatation but to the fact that the



FIGURE 79 Patent ductus arteriosus Contrast visualization in left anterior oblique position shows the localized bulge of the descending aorta below the isthmus at the site of insertion of the ductus This film was made postoperatively Clips are seen at the site of the obliterated ductus arteriosus. The aortic sign is regularly found in patent ductus arteriosus

pulmonary artery is drawn upward toward the aortic isthmus by a shortened ductus arteriosus. The pulsations of the pulmonary artery as observed fluoroscopically or in the roentgenkymogram are increased in amplitude (Fig. 78).

The heart is not regularly enlarged in patent ductus arteriosus, rarely to any considerable degree. Enlargement of the left ventricle is seen oftener than right ventricular enlargement. This is due to increased work of the left ventricle since a considerable portion of its output may be shunted into the pulmonary artery through the patent ductus arteriosus.

Angiocardiographic study with diodrast reveals a pathognomonic sign that [illegible] ary roentgenography. In almost all cases [illegible] on there is seen a localized dilatation of [illegible] the aortic isthmus at the site of attachment of the ductus arteriosus (Fig. 79).

Careful roentgenologic examination is of utmost importance where patent ductus arteriosus is suspected to assist in proper selection of cases for surgical correction of this condition. Wherever possible the angiocardiographic method and catherization recordings of pulmonary artery pressure and oxygen saturation should be employed before surgical inter-

vention is attempted, although the diagnosis may be made with reasonable certainty without these procedures as a rule.

Pulmonic Stenosis: Marked right ventricular hypertrophy is regularly observed in pulmonic stenosis. The enlargement is due chiefly to hypertrophy, rather than dilatation as in patent interatrial septum. Hypertrophy of the body of the right ventricle (inflow tract hypertrophy) produces a characteristic configuration. The apex becomes elevated producing an increased rounding of the lower left heart border, the lower portion of the contour being formed by the right ventricle (*coeur-en-sabot*). The dimensions of the cardiac shadow may not be considerably increased, although the right heart border tends to be accentuated due to right auricular enlargement. Hypertrophy of the body of the right ventricle is evident, too, in the left anterior oblique position, being recognized as a forward bulge of the anterior heart border The pulmonary artery might be expected to be small in isolated pulmonic stenosis but dilatation of the pulmonary artery distal to the stenosis is present not infrequently. The smaller branches of the pulmonary artery, however, are not dilated as is seen regularly in patent interatrial septum and frequently with patent ductus arteriosus.

Angiocardiographic examination as in other conditions with right ventricular hypertrophy, such as cor pulmonale, may demonstrate a displacement of the interventricular septum toward the left ventricle, with convexity of the septum to the left instead of toward the right as is normally found.

Isolated pulmonary stenosis is much commoner than has hitherto been supposed. Fully twenty-five per cent of cases diagnosed as tetralogy of Fallot have isolated pulmonic stenosis, a procedure now curable by the Brock procedure of pulmonary artery valvulotomy.

Subisthmic Aortic Stenosis: The murmur in subisthmic aortic stenosis is maximal at the aortic rather than pulmonic area. Clinical and roentgenologic features are identical with aortic stenosis of rheumatic origin, *i e., hypertrophy of left ventricle.*

Coarctation of the Aorta: The characteristic roentgenologic features in coarctation of the aorta include moderate dilatation and hypertrophy of the left ventricle, and dilatation of the ascending arch of the aorta A pathognomonic sign, which is not always present, is scalloping of the inferior *margins of the ribs posteriorly due to increased size of the inter*costal arteries which form a collateral circulation (Fig. 80). Angiocardiographic visualization of the aorta demonstrates narrowing at the site of coarctation in the region of insertion of the ductus arteriosus (Fig. 81). The dilated internal mammary arteries can also be visualized. The roentgenologic findings together with the clinical features of elevated blood pressure in the arms, and murmurs over the base and interscapular region permit the diagnosis of coarctation of the aorta to be made with some certainty.

Another group of congenital cardiac lesions is characterized by murmurs heard more widely over the precordium. These are associated with a defect in the interventricular septum.



FIGURE 80 Coarctation of the aorta The left ventricle is enlarged, scalloping of the inferior margins of the ribs posteriorly is present.



FIGURE 81 Coarctation of the aorta. Contrast visualization in left anterior oblique position. Note narrowing and irregularity of aorta at site of coarctation just distal to the aortic arch. The dilated internal mammary artery is visible behind the sternum

Interventricular Septal Defect: This lesion is characterized by absence of enlargement, or relatively slight enlargement of either or both ventricles (Fig. 82). The negative roentgenologic findings, however, are helpful in suggesting the presence of an interventricular septal defect when a loud

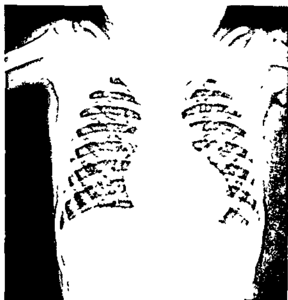


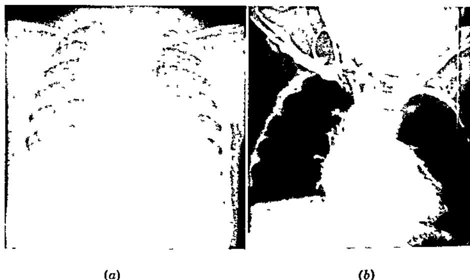
FIGURE 82. Ventricular septal defect, moderate cardiac enlargement chiefly of the left ventricle

long systolic murmur replacing the first heart sound is heard widely over the precordium with maximal intensity in the third or fourth interspace to the left of the sternum. A diphasic Q-R-S complex in all the standard leads of the electrocardiogram is frequently observed in this condition.

Angiocardiographic examination in interventricular septal defect may reveal reopacification of the right ventricle after the diodrast has circulated to the left cardiac chambers due to a left to right shunt. Cardiac catheterization studies of pressure curves and oxygen saturation in the right ventricle permit more certain diagnosis

Tetralogy of Fallot: Patency of the interventricular septum is very commonly associated with dextroposition of the aorta (origin largely from the right ventricle), pulmonic stenosis, and right ventricular hypertrophy. The roentgenologic changes are due predominantly to pulmonic stenosis causing right ventricular hypertrophy, typically producing a *coeur-en-sabot* configuration as seen in pulmonic stenosis (Fig. 24). Differentiation from isolated pulmonic stenosis is indicated by a more extensive murmur (murmur of septal defect plus pulmonic stenosis) and the greater degree of cyanosis. The pulmonary vasculature is sparse in the roentgenogram.

Angiocardiography reveals simultaneous filling of the aorta and pulmonary artery, and the pulmonary artery and branches are seen to be very small (Fig. 83). Cardiac catheterization is a valuable diagnostic aid, and should be carried out preparatory to surgery.



(a) (b)

FIGURE 83 Tetralogy of Fallot: (a) Teleoroentgenogram shows generalized cardiac enlargement (b) Two seconds after intravenous injection of diodrast the right ventricle and pulmonary artery, and the left ventricle, aorta and brachiocephalic vessels are simultaneously visualized indicating shunt The arch of the aorta in this case is situated to the right of the spine The pulmonary artery and branches are small

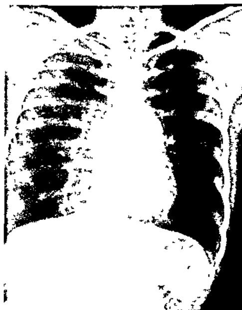


FIGURE 84. Tetralogy of Eisenmenger This lesion is similar to tetralogy of Fallot except that there is dilatation of the pulmonary artery instead of pulmonic stenosis.



FIGURE 85 Tetralogy of Eisenmenger in diodrast visualization shows simultaneous filling of aorta, which is small, and markedly dilated pulmonary artery The left to right shunt is relatively small in this lesion and the degree of cyanosis is therefore less than in tetralogy of Fallot (*a*) Pulmonary artery, (*b*) aorta, (*c*) great vessels.



FIGURE 86 Right-sided aortic arch The aorta descends on the right instead of on the left side

Tetralogy of Eisenmenger: This rare syndrome is similar to tetralogy of Fallot except that pulmonary artery dilatation instead of pulmonic stenosis is present. In addition to right ventricular hypertrophy the pulmonary artery may be greatly dilated (Fig. 84). Angiocardiography reveals simultaneous filling of the aorta and pulmonary artery and the pulmonary artery is observed to be increased in size (Fig. 85). The degree of shunting



FIGURE 87 Right-sided aortic arch (same case as Fig. 86). The curve of the esophagus around the aorta is reversed Aorta is visualized with diodrast in the overpenetrated roentgenogram

in tetralogy of Eisenmenger is less than in tetralogy of Fallot, and cyanosis may be minimal or elicited only when venous return to the right side of the heart is increased as following exercise or crying.

Other Cyanotic Lesions: There are several additional congenital lesions of the heart accompanied by cyanosis. In most of these the morphologic and dynamic alterations are so extreme that death occurs early in life. Among such lesions may be mentioned defective development of the right ventricle with tricuspid atresia, truncus arteriosus, transposition of the great vessels, and cor biatriatum triloculare. Roentgenologic study of the heart and pulmonary vasculature help in differentiating these conditions. Defective development of the right ventricle with tricuspid atresia: The circulation is maintained by virtue of a patent interatrial septum and patent ductus arteriosus allowing blood to by-pass the nonfunctioning right ventricle. There is a decrease in the right ventricular shadow best seen in oblique views, and a decrease or absence of the pulmonic conus and pulmonary artery shadow together with a paucity of pulmonary vascular markings. The left ventricle is enlarged. Truncus arteriosus: Marked right ventricular hypertrophy occurs, with absence of the shadow of the

pulmonic conus and main pulmonary artery. The small pulmonary vessels are inconspicuous, a fuzziness may be present adjacent to the vascular pedicle caused by dilated bronchial arteries supplying collateral circulation to the lungs. Prominence of the aortic arch helps to distinguish this lesion from others such as tetralogy of Fallot.

Transposition of the Great Vessels: Unlike truncus arteriosus the vascular pedicle shadow is narrow in the posteroanterior position but broader in oblique views. The pulmonic conus shadow is absent but the

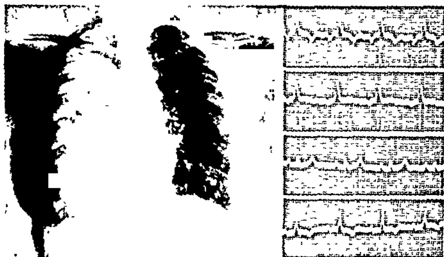


FIGURE 88 Dextrocardia The heart is normal but is reversed in its position The electrocardiographic changes are typical

peripheral pulmonary vascular shadows are not diminished and may show congestion. Both left and right ventricles are greatly enlarged A shunt at some point between pulmonic and systemic circulations is necessary to sustain life in this condition Cor biatriatum triloculare (single ventricle): Cardiac enlargement of slight to moderate degree may be present. There is a marked prominence of the pulmonic conus and pulmonary congestion is apt to be present.

Persistent Right Aortic Arch: This anomaly is recognized by the presence of the aortic knob on the right instead of its usual position on the left. The aortic impression on the esophagus is reversed, *i e.*, the esophagus curves to the right instead of to the left around the aorta in the posteroanterior view, and curves forward instead of backward in the right anterior oblique position (Fig. 86, 87). The abnormal course of the esophagus occasionally causes dysphagia. Another symptom we have observed is impaired circulation in the left upper extremity presumably due to an anomalous origin and course of the left subclavian artery. Another aortic anomaly, not rare, is vascular ring. This, as well as double aortic arch, may cause pressure symptoms on the trachea or esophagus It is best studied by angiocardiography.

Dextrocardia: Dextrocardia may be associated with transposition of all the viscera (situs inversus) or may occur alone (Fig. 88). It is surprising how often the diagnosis escapes clinical detection, and it is frequently missed in the roentgenogram as well unless attention is paid to the lead markings on the roentgenogram indicating the right and left sides. Other types of dextrocardia occur due to congenital rotation of the heart, or in association with miscellaneous types of congenital heart lesions. Congenital dextrocardia is to be differentiated from acquired dextrocardia which



FIGURE 89 Cor pulmonale. There is marked enlargement of the right ventricle The etiology in this thirty-three-year-old female was bronchial asthma

results from displacement of the heart to the right due to such causes as pulmonary fibrosis with traction on the heart, or eventration of the diaphragm.

There are several other rare congenital anomalies which are not characterized by any distinct clinical or roentgenological features. Bicuspid aortic valve is not an uncommon lesion, but since it does not interfere with cardiac dynamics there are no diagnostic findings. This condition is important chiefly as a predisposing cause of subacute bacterial endocarditis

Cor Pulmonale: Enlargement of the right ventricle and atrium and right sided cardiac failure may result from protracted obstruction to the pulmonary circulation with its attendant pulmonary hypertension. Numerous etiological factors may produce the cor pulmonale syndrome, such as bronchial asthma, emphysema, and pulmonary fibrosis, marked thoracic deformity (kyphoscoliotic heart disease), pulmonary arteriolar sclerosis, multiple embolization in the smaller pulmonary vessels, etc.

The roentgenological appearance may be deceptive in that considerable right ventricular hypertrophy may exist without appreciably altering the

posteroanterior cardiac configuration or size. This is particularly true if marked emphysema is present, where the enlarged thorax and low diaphragm may cause the heart to appear relatively normal or even small. The pulmonary artery is usually quite prominent. Right ventricular enlargement is best demonstrated in oblique views. In the left anterior projection hypertrophy of the body of the right ventricle (inflow tract) is revealed by a forward bulge of the anterior surface of the heart Enlargement of the conus of the right ventricle (outflow tract) is observed in the



FIGURE 90 Cor pulmonale Same case as in Fig 89 Right anterior oblique position The esophagus pursues a normal vertical course, indicating that the left atrium is not enlarged The cause of the pulmonary hypertension, therefore, is due to an obstructive lesion in the pulmonary circuit

slight right anterior oblique position. When the right ventricular enlargement is marked the conus of the right ventricle may occupy the upper left heart border (Fig. 89). Cor pulmonale can be differentiated from right ventricular enlargement secondary to left heart failure by observing the course of the esophagus in the right anterior oblique position. The left atrium is found to be normal in size (Fig. 90), whereas in left heart failure, particularly secondary to mitral valvular disease left atrial enlargement is indicated by backward displacement of the esophagus.

While marked deformities of the thoracic skeleton, as in extreme kyphoscoliosis may cause right ventricular hypertrophy and the cor pulmonale syndrome, it may be extremely difficult to evaluate the size of the heart, since it may be displaced and distorted in configuration (Fig. 8). Other diagnostic procedures, such as circulation time studies, may be of greater value than roentgenograms in such cases in helping to determine whether symptoms are due purely to pulmonary embarrassment or whether there

is associated cardiac failure. The diagnosis of cor pulmonale is made far too often. Pulmonary hypertension is not synonymous with cor pulmonale any more than hypertension is with hypertensive heart disease. Patients with pulmonary disease may have pulmonary hypertension but their symptoms are far oftener due to pulmonary insufficiency than to cardiac embarrassment. In an extensive series of patients with advanced pulmonary disease we studied, cardiac function tests (output response to exer-

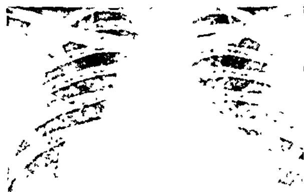


FIGURE 91 Pericardial effusion "Typical" bottle-shaped configuration with loss of normal cardiac contours The configuration in pericardial effusion is not commonly as characteristic.

cise) was almost invariably normal. The diagnosis of cor pulmonale should be made only when there is evidence of right heart failure. The commonest cause is not pulmonary disease, but antecedent left heart failure.

Pericardial Effusion: The clinical picture of acute pericarditis with effusion is quite characteristic and a diagnosis frequently may be made even though the effusion is small in amount. The capacity of the normal pericardium to distend is quite limited and when a fluid collection develops rapidly as in hemopericardium due to trauma or rupture of an aortic aneurysm the presence of a relatively small quantity of fluid may cause cardiac tamponade.

Frequently, however, pericardial effusion of whatever etiology develops over a longer period of time and the pericardium is gradually distended so that very considerable amounts of fluid may accumulate without impeding the circulation. Other features, too, such as pain and a friction rub which characterize acute pericarditis, are often lacking in chronic pericardial effusion. Even the electrocardiogram which is a valuable diagnostic aid in acute pericarditis, is of less value when the effusion is of longer duration. In contrast to characteristic serial electrocardiographic patterns which

occur in acute pericarditis, nonspecific changes, such as low voltage of the ventricular complexes and variable T wave abnormalities, may be observed, and at times the electrocardiogram appears relatively normal.

Since the various clinical features may be inconspicuous the existence of pericardial effusion even of appreciable size may be unsuspected, and its presence may be disclosed inadvertently, during routine roentgen examination of the chest. Roentgenologic examination provides the most certain diagnostic evidence, apart from paracentesis, when pericardial effusion of any considerable amount is present.

The roentgen appearance of pericardial effusion frequently is characterized by such terms as bottle shaped, bag shaped or triangular shaped. It should be emphasized that the appearance of pericardial effusion in the roentgenogram is extremely variable. There is no one configuration typical of pericardial effusion as contrasted with enlargement of the heart, all the more since the shape of the enlarged heart varies greatly, too, depending on the chambers involved. If there is any configuration suggestive of effusion it is generalized enlargement of the cardiac shadow with loss of the characteristic shape due to obliteration of the normal contours of the chambers and great vessels (Fig. 91) No alteration in shape is evident until a large amount of fluid has accumulated and it is generally accepted that effusion less in amount than ten to twelve ounces cannot be discerned with any certainty.

Several authors have called attention to a change in the angle at the junction of the right lower heart border and the diaphragm. We have not found his sign to be of any value since the right cardiophrenic angle, which varies greatly in enlarged hearts in the absence of effusion, may remain either unchanged or become increasingly acute or conversely more obtuse.

When the effusion is large and fluid extends upward distending the pericardium near its attachment to the great vessels, obliterating the aortic arch and pulmonary artery curves, the shadow of the vascular pedicle becomes foreshortened and broadened. This change in the shape at the base may be accentuated by examining the patient in the recumbent position with the head and chest tilted downward. A marked shift in the shape of the cardiac shadow on rotation from the right to left lateral recumbent positions is a helpful sign, but such shifts must be interpreted with reserve unless marked, since the position and shape of the enlarged heart too may alter with shift in body position.

A rapid change in size of the cardiac shadow on serial examination is more suggestive of pericardial effusion than its appearance at any one time. Contrary to usual belief, the heart, as revealed by roentgen study, does not as a rule dilate to any considerable degree in heart failure It is unusual to observe marked changes in the size and shape of the cardiac shadow over a short period of time in any of the commoner types of heart disease. Roentgenologic examination at frequent intervals is therefore an aid in the diagnosis of pericardial effusion when progressive changes in the size of the cardiac shadow can be demonstrated on successive examinations.

In acute pericardial effusion the restraining influence of the pericardium may cause cardiac tamponade. Signs of obstruction to the circulation play a prominent part in the clinical picture, such as paradoxical pulse, small

pulse pressure indicative of diminished cardiac output, and increased venous pressure. In chronic pericardial effusion, however, there may be remarkably little or no interference with the circulation since the pericardium is gradually distended and its capacity is greatly increased. Clear lung fields, free of any pulmonary congestion, are frequently observed in chronic pericardial effusion. When the heart is markedly enlarged as the result of heart disease on the other hand, some degree of pulmonary congestion is usually present. Marked enlargement to the right as seen in massive enlargement of the left atrium and tricuspid valvular disease may simulate the roentgenologic appearance of pericardial effusion, but these lesions may be clinically differentiated from pericardial effusion As a general rule enlargement of the cardiac shadow considerably to the right in the absence of peripheral and pulmonary congestive changes is a typical finding in pericardial effusion.



FIGURE 92. Roentgenkymogram in case with pericardial effusion shows almost total absence of pulsations along both heart borders. The aortic pulsations are not obliterated

Characteristically, pulsations along both heart borders are greatly diminished in the presence of a considerable effusion into the pericardium, but this sign must be interpreted with reserve. The pulsations of the lower heart borders are frequently greatly diminished when the heart is markedly enlarged due to any type of organic heart disease. Study of the pulsations in the left anterior oblique position is of value. Normally vigorous systolic pulsations of large amplitude are observed over the lower posterior left ventricular border and even in the presence of marked cardiac enlargement the pulsations do not diminish to the same degree as the apical

pulsations in the posteroanterior position. Pericardial effusion accumulates early in this region, and in the left enterior oblique position the left ventricular pulsations become obscured as fluid collects in the inferior pericardial recess. When the effusion is large the lower posterior cardiac contour may be seen to sag into the diaphragm indenting the stomach. Inflation of the stomach with an effervescent mixture aids study of the pulsations of the inferior cardiac surface



FIGURE 93 Same case as Fig 92 one month later after resolution of pericardial effusion The cardiac shadow is much smaller in size and normal amplitude of pulsations is now present

The cardiac pulsations are best studied by means of roentgenkymography (Fig. 92, 93). While diminution of the cardiac pulsations, as mentioned, is not specific, the disparity between the amplitude of pulsations of the descending aorta, which tend to remain normal, and the greatly diminished amplitude of left ventricular pulsations is suggestive of pericardial effusion.

It has been reported by some that a double density distinguishing the heart shadow within the borders of the effusion can be observed occasionally in cases of pericardial effusion, but the validity of this sign has been denied by most authoritative observers, nor have we ever encountered this finding in a case of pericardial effusion. Holmes investigated this question experimentally by injecting fluid into the pericardial sac of dogs and was not able to discern any difference in radiographic density between the heart and pericardial contents.

Contrast visualization of the heart by means of diodrast offers a method, first described by the authors, whereby the cardiac chambers may be

clearly outlined within the effusion. An overpenetrated roentgenogram exposed two to three seconds after the rapid injection of 30 to 45 cc. of seventy per cent diodrast visualizes the right auricle, and the outline of this chamber can be clearly demarcated from any surrounding pericardial effusion as in the case illustrated in Fig. 94. Visualization of the other



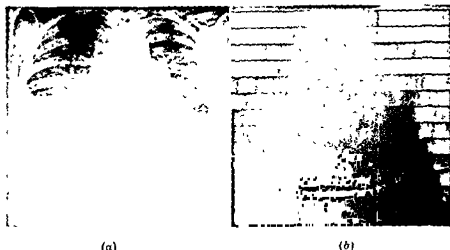
FIGURE 94 Diodrast visualization of right auricle within border of pericardial effusion. The cardiac shadow cannot be distinguished from that of the effusion, but this may be accomplished by exposing the film a few seconds after intravenous injection of seventy per cent diodrast The right auricle is delineated within the border of the pericardial effusion. (*a*) Right auricle, (*b*) pericardium If this technic is carried out during roentgenkymography further distinction between the contour of the heart and the pericardium is evident. The cardiac pulsations within the effusion are found to be of normal amplitude whereas the pulsations at the periphery of the effusion are greatly damped.

cardiac chambers with diodrast is not as satisfactory as the right auricle unless the multiple exposure technic is employed, due to the dilution of the dye in the pulmonary vascular bed, uncertainty as to the speed of the circulation of the diodrast through the lungs to the left side of the heart, and the possibility of exposing roentgenograms when the heart is contracted and relatively empty in systole. However, the right auricle can be visualized regularly without difficulty and the finding of a double contour provides a pathognomonic sign of pericardial effusion.

Localized fluid collections in the pericardium in the form of cysts have been described. This condition, and herniation of the pericardium, both of which are rare, produce an eccentric cardiac contour.

Constrictive Pericarditis: In contrast to chronic pericardial effusion where the markedly enlarged cardiac shadow is often unaccompanied by any signs of cardiac failure, the characteristic features of constrictive pericarditis are signs of pulmonary and peripheral congestion in the presence

of a heart of relatively normal size (Fig. 95). The characteristic roentgenologic features include the following: (1) The heart is normal in size in the majority of cases, unless there has been pre-existing heart disease. Constrictive pericarditis is not usually on a rheumatic basis and the etiology is often obscure. If the adhesions are chiefly over the left ventricle or atrium obstruction to blood flow may cause enlargement of the right cardiac chamber. (2) Marked generalized diminution of the cardiac



(a) (b)

FIGURE 95 (a) Constrictive pericarditis The contour of the cardiac shadow, which is not appreciably [illegible] hat irregular (calcification is [illegible] congestion is present A re- [illegible] (b) Roentgenkymogram of [illegible] mplete absence of pulsation along the heart border due to the constricting pericardium

pulsations is present. This is best demonstrated by roentgenkymography, it is also evident on fluoroscopy. (3) Irregularity in the cardiac contour is occasionally observed due to pleuro-pericardial adhesions; distinct adhesions may be seen. (4) Calcification of the pericardium is a helpful sign when present, although it should be noted that extensive calcification of the pericardium may be present in the absence of any obstruction to the circulation (Fig. 96). Calcification of the pericardium is best detected in the left anterior oblique position employing overpenetration technic. (5) Congestive changes in the lung fields may be present. Pleural effusion is very frequent.

Roentgenologic study is important whenever constrictive pericarditis is suspected for the findings are frequently diagnostic, and may provide specific indication for surgical intervention Following pericardial resection the return of normal cardiac dynamics may be observed in the roentgenkymogram, the amplitude of ventricular pulsations increasing to normal.

Roentgenologic study of the heart is of interest in various diseases where the heart is secondarily involved. In these states enlargement of the hea[illegible] is often generalized and mensuration is apt to be of greater value tha[illegible]

study of the individual chambers in deciding whether enlargement is present.

Hyperthyroidism: Unless hyperthyroidism is complicated by antecedent heart disease, enlargement of the heart is rarely striking even when there is marked and longstanding elevation of the basal metabolic rate. Slight to moderate enlargement is found in approximately half the cases with Graves' disease. In cases with auricular fibrillation slight enlargement of the left atrium may be found, but this is never comparable to the degree of left atrial enlargement that occurs when auricular fibrillation is due to mitral valvular disease. Frequently, the pulmonary artery is prominent but this finding is nonspecific since it is observed in normal subjects of asthenic habitus. The rate and amplitude of the cardiac and vascular pulsations is greatly increased in hyperthyroidism reflecting the increased cardiac output.



FIGURE 96. Calcification of the pericardium, left anterior oblique projection. A calcified pericardial plaque is seen along the lower anterior surface of the heart. This was not visible in the posteroanterior projection. Extensive calcification of the pericardium may be present without causing any symptoms.

Myxedema: Generalized enlargement of the cardiac shadow is a common finding in myxedema. The size of the heart regresses rapidly with thyroid therapy. When marked enlargement is present pericardial effusion should be suspected; this is not at all a rare occurrence in myxedema (Fig. 97). Several of the findings considered typical of the myxedema heart undoubtedly in many cases are due in part or entirely to associated pericardial effusion, *i. e.*, enlargement of the cardiac shadow, diminished amplitude of pulsations, distant heart sounds, inversion of the T waves and low amplitude of the ventricular complexes in the electrocardiogram

Beriberi Heart: Thiamin deficiency, when prolonged, results in a peculiar type of cardiac decompensation, the right cardiac chambers becoming enlarged with negligible involvement of the left ventricle and atrium. The pulmonary fields remain free of congestion, despite well marked edema and other peripheral signs of right heart failure. Pericardial effusion has been described in this condition.

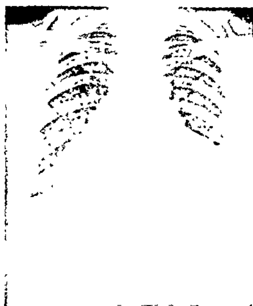


FIGURE 97 Pericardial effusion in myxedema With thyroid therapy, the effusion resorbed and the size of the cardiac shadow decreased markedly

Addison's Disease: An unusually small size of the heart is typical of Addison's disease and is due to decreased volume of blood within the heart as well as in part to a small myocardium With administration of desoxycorticosterone acetate the size of the heart increases. Numerous instances have been reported of the development of cardiac enlargement and heart failure following excessive doses of adrenal cortical hormone, due to the development of hypertension and salt retention.

Glomerulonephritis: Heart failure occurs very commonly in acute glomerulonephritis and moderate cardiac enlargement may be seen. When pulmonary edema is present it is due not only to cardiac failure but in large measure to vascular damage with exudation into the pulmonary parenchyma. A central type of pulmonary congestion is often observed in contrast to the basal congestive changes seen in chronic cardiac decompensation. These changes are reversible and the heart returns to normal concomitant with clinical improvement.

Anemia: When anemia of severe degree is prolonged, cardiac enlargement ensues. This regresses rapidly with adequate therapy. Cardiac changes are particularly striking in sickle cell anemia and the heart is often considerably enlarged. Differentiation from rheumatic mitral val-

vular disease may be extremely difficult since apical murmurs occur regularly and other features typical of rheumatic fever such as prolongation of the P-R interval and joint pains are present in a large percentage of cases. An important sign differentiating sickle cell anemia from mitral valvular disease is the absence of backward displacement of the esophagus in sickle cell anemia in contrast to its almost regular occurrence in mitral valvular disease.

Polycythemia: When polycythemia is secondary to chronic pulmonary disease or congenital heart disease the roentgenologic findings are determined by the underlying disease (*e. g.*, right ventricular enlargement in cor pulmonale). In polycythemia vera slight to moderate generalized cardiac enlargement may be present, as the increased blood viscosity augments the work of the heart. Due to the increase in blood volume there is a noticeable increase in the pulmonary vascular markings. Small nodular shadows in the pulmonary fields have been described.

Myocarditis: Numerous infections and toxic agents may cause myocarditis. Most frequent perhaps are diphtheritic and typhoid myocarditis although many other infections may provide a background for the development of myocarditis, particularly those of the respiratory tract. Severe and protracted myocardial damage may result from these and other types of myocarditis (*e. g.*, acute isolated or Fiedler's myocarditis). Serial observation of the size of the heart is a helpful prognostic guide. Cardiac enlargement, chiefly dilatation rather than hypertrophy, and symptoms of impaired cardiac reserve may persist for a considerable time after the acute stages of myocarditis. Low grade chronic myocarditis appears to be responsible for cardiac enlargement found in cases of so-called idiopathic hypertrophy of the heart, since autopsy in such cases regularly shows evidence of myocardial disease.

Glycogen Storage Disease: (Von Gierke's Disease.) Marked enlargement of the heart in infants and children in the absence of any evident etiological factor such as congenital or rheumatic heart disease should arouse suspicion of glycogen storage disease. Enlargement of the liver and characteristic laboratory findings (*i. e.*, acetonuria, low fasting blood sugar, abnormal sugar tolerance curves, failure of blood sugar to rise with epinephrine, and marked insulin sensitivity) help to establish the diagnosis.

Pregnancy: Important circulatory changes occur in pregnancy. It has been shown that the placenta acts much like an arteriovenous aneurysm, and increased cardiac output and blood volume in pregnancy are probably to be attributed to this factor. Slightly physiological enlargement of the heart occurs in the last trimester of pregnancy. Due to hypervolemia the pulmonary vascular markings become somewhat accentuated. Positional changes result from elevation of the diaphragm, the heart becoming more transversely situated (Fig. 98). Slight backward displacement of the esophagus which is ordinarily a dependable sign of left atrial enlargement may be present normally in late pregnancy. Because of these changes, it is important wherever heart disease complicates pregnancy that careful study be carried out in the early months of pregnancy rather than in the last trimester, at which time findings simulating those in organic heart disease may occur normally.

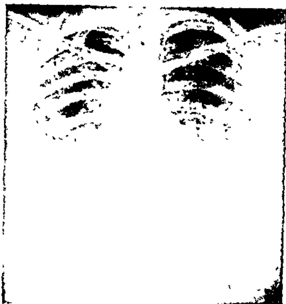


FIGURE 98 Pregnancy. Slight physiological enlargement of the heart occurs in the last trimester of pregnancy. The heart becomes transversely placed due to elevated position of the diaphragm Increase in pulmonary vascular markings is frequently seen.

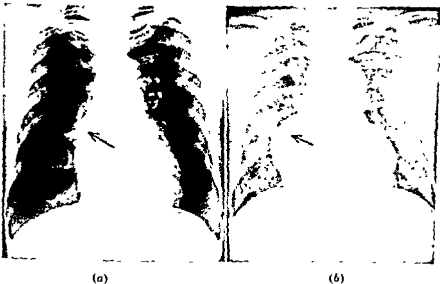


FIGURE 99. (a) Tumor of the heart along upper right heart border (b) Same case two years later showing marked increase in size of the neoplasm. Contrast visualization with diodrast showed extension into right auricle and displacement of right ventricle Etiology probably sarcoma of the right auricle The electrocardiogram showed inversion of T waves in Leads II and III, possibly due to pressure on right coronary artery

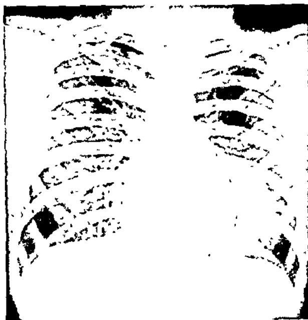


FIGURE 100 Tumor along the left heart border; probably a benign pericardial *neoplasm* The tumor was difficult to differentiate from the cardiac shadow Roentgenkymogram showed pulsations of the border of the ventricle within the margin of the tumor Patient was asymptomatic and the lesion was detected *inadvertently* during examination for acceptance in the Navy. The only clinical finding was a systolic apical murmur.



FIGURE 101. Echinococcus cyst in pericardium Calcified cyst is seen in the [illegible] Skin test [illegible] d Q waves [illegible] ressure on

Arteriovenous Aneurysm: The great increase in cardiac output that may result from arteriovenous communication leads to compensatory generalized cardiac dilatation and hypertrophy. With surgical correction the heart size regresses to normal.

Tumors of the Heart: Tumors of the heart and pericardium though rare are most varied in etiology, size and situation and accordingly no characteristic roentgenologic findings can be described Those which are externally situated may produce an eccentric configuration. Examination in oblique positions, and special technic such as roentgenkymography and contrast angiocardiography occasionally may provide valuable information Illustrations of cardiac tumors are shown in Fig. 99 to 102. Metastatic invasion *of the heart is common, particularly in lymphomas and in cancer of the* lung.



FIGURE 102. "Tumor" projecting from left heart border in fifteen year old girl. Roentgenkymogram showed systolic expansion, suggesting ventricular aneurysm Autopsy disclosed ventricular aneurysm presumably due to anomaly in development of the muscle bundles



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Cardiac Catheterization

The introduction of a catheter into any of the cardiac chambers is called cardiac catheterization. More specifically, right-sided cardiac catheterization refers to the procedure of inserting a catheter into the right side of the heart from a peripheral vein, while left-sided cardiac catheterization includes several techniques by which a catheter may be passed into the left atrium or ventricle.

HISTORY

In 1929, Forssmann, using himself as a subject, performed the first right-sided cardiac catheterization in a human being. Ara, in 1931, and Monez, in 1932, used a similar procedure to inject radiopaque substances into the pulmonary vascular bed. Cournand, in 1941, and McMichael, in 1943, utilized cardiac catheterization to gather physiologic data concerning the vascular system in health and disease. Hellems and Dexter in this country and Lagerloff and Werko in Sweden extended the technique in 1948 by showing that pressure pulses recorded with the catheter tip wedged in a small pulmonary artery were comparable to those in the pulmonary veins and left atrium. In 1950, Zimmerman carried out the first left-sided cardiac catheterization in man, passing a catheter from the aorta into the left ventricle. Finally, in 1953, the accomplishment of the direct puncture of the left atrium in man by Allison and by Bjork lead to the techniques of left-sided cardiac catheterization in current use.

INDICATIONS AND CONTRAINDICATIONS

It is difficult to define clearly the indications for and contraindications to cardiac catheterization since in each patient the small inherent risk associated with the procedure must be weighed against the importance to the patient of the data sought. Not only do the indications vary from clinic to clinic, but indeed they vary in any one clinic with the passage of time and the ability of the clinician to evaluate accurately patients with heart disease. In general, however, any of the following reasons may be considered adequate for undertaking cardiac catheterization.

1. As an aid in diagnosis of the patient whose cardiovascular disease remains undefined despite other clinical and laboratory studies.
2. As a means of determining the magnitude of circulatory derangements present.
3. As a way of assessing the course of a cardiovascular disease.

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4. As a method of evaluating the effect on the heart of either medical or surgical therapy.

There are only two well-recognized contraindications to cardiac catheterization: recent myocardial infarction and paroxysmal ventricular tachycardia. Subacute bacterial endocarditis, pulmonary embolism, active rheumatic fever, severe congestive failure and acute illness constitute relative contraindications in that catheterization should be delayed until the active process has become quiescent, or until the patient has shown a maximal response to therapy. The risks associated with right-sided cardiac catheterization appear to be increased in patients with Ebstein's disease, ischemic heart disease, and severe forms of pulmonary hypertension. Right-sided cardiac catheterization is attended by an added risk in the presence of a left bundle branch block, since the induction of a right bundle branch block may lead to cardiac standstill and death. Severely ill and excitable patients may tolerate the procedure poorly, and data obtained under such circumstances may be difficult to interpret.

PREPARATION OF PATIENTS

General: Before cardiac catheterization is undertaken, the physician making the study should take a complete history, perform a careful physical examination, and carry out fluoroscopic and electrocardiographic studies He must then decide whether the procedure is indicated, and if it should be performed at once, or delayed. Prior to catheterization most patients appreciate an explanation of the purpose of the study, the nature of the procedure and the significance of symptoms they may experience. In some instances it is useful to acquaint the patient with the laboratory and its equipment.

Adults: Adult patients are deprived of all food and fluid for eight hours prior to right- or left-sided cardiac catheterization. Penicillin (600,000 units) is given one or two hours prior to the study, and once daily for two days following its completion Premedication consists of 100 mg. of Nembutal one hour before catheterization, and, in some nervous or excitable patients, 50 to 100 mg. of Demerol.

Children: In very small infants, fasting is not required. Indeed, a bottle used as a pacifier may be essential to the completion of a successful study. Penicillin (300,000 units) is given one to two hours before the study and once daily for two days after its completion. The use of several combinations of drugs prior to cardiac catheterization has obviated the necessity for general anesthesia. Morphine sulfate, in intra-muscular doses of 1 mg. per 10 lbs. of body weight, and phenobarbital sodium, 60 mg. per 10 lbs of body weight, are given one hour prior to the study. Regardless of weight, the maximum initial dose of morphine sulfate is 8 mg., and of phenobarbital sodium, 180 mg. A mixture—containing in each milliliter: Demerol 25 mg., Phenergan 6.25 mg., and chlorpromazine 6.25 mg.—has proved equally useful when injected one hour prior to the study in doses of 1 ml. per 30 lbs of body weight. No more than 2 ml. of this mixture is given initially, regardless of the patient's weight. Occasionally during the procedure it may be necessary to give a small supplementary dose of medication.

EQUIPMENT

Cardiac catheterization should be performed in a room specifically set aside for this purpose. The room should be large enough to accommodate the necessary equipment and to permit free access to the subject from all sides of the fluoroscopic table. Ideally, a small laboratory for the analysis of blood and respiratory gases should be in close proximity to the catheterization room.

Fluoroscope: The fluoroscopic unit should permit satisfactory visualization of the catheter in the thoracic cage with the least radiation exposure to the subject and to the members of the catheterization team. The responsible member of the catheterization group should know the radiation characteristics of the fluoroscopic unit in use The total period of radiation exposure for each study should be measured by an automatic timer and should not lead to a radiation dosage of more than 80 roentgens to the subject In all instances, x-ray exposure should be of the smallest amount compatible with the performance of a satisfactory study

Members of the catheterization group should protect themselves from excessive radiation exposure at all times by using leaded aprons and gloves. The radiation exposure received by each individual should be measured with a film badge.

Manometers and Recording Devices: A satisfactory manometer should be relatively stable, easily calibrated and readily maintained in a sterile state. Its physical characteristics should be such that it records faithfully pressure changes occurring within the heart from −20 to +300 mm of Hg at frequencies of up to 25 cycles per second.

During cardiac catheterization, intravascular pressures are most often measured by electromanometers which convert pressure energy to electrical signals. Three types of electromanometers are currently in use:

1. In a capacitance manometer, the diaphragm functions as one plate of a condenser whose capacitance is altered as the diaphragm moves in response to an applied pressure.

2. In a strain gauge manometer the tensions, together with the resistances, of several small wires attached to the undersurface of the diaphragm are altered by changes in the diaphragm's position

3. In an inductance manometer, deformation of the diaphragm moves a core in a magnetic field, thereby changing the field's inductance.

Ordinarily, transducers of this type contain a bridged circuit in which movement of the diaphragm leads to imbalance of the circuit. The magnitude of the change is then amplified and recorded by various types of oscilloscopes and oscillographs.

Surgical and Medical Supplies: A table close to the operating physician should hold hemostats, knives, tissue scissors, retractors, suture material, suture needles, syringes, hypodermic needles, several medicinal bottles, and drapes of sufficient size to maintain a fairly large sterile area around the exposed vein. The physician passing the catheter should be gloved and gowned so that sterility may be maintained in the operative field.

Medical supplies should include pressor drugs such as epinephrine, norepinephrine and Neo-synephrine; antiarrhythmic drugs such as Pronestyl, quinidine, digitalis, Isuprel and molar lactate. For emergencies, resuscitative equipment, including tracheal airways and a means of ventilating the subject, as well as defibrillators and electrical pacemakers, should be ready for use at all times.

Catheters: Right-sided cardiac catheterizations are ordinarily performed with curved-tipped radiopaque nylon catheters 100-125 cm. long whose outside diameters range from 1.3 mm. (4F) to 3.2 mm. (10F). In infants, catheters 50-70 cm. in length with thin outside walls are used when regional angiocardiography is contemplated as part of the study. Catheters with manometers, sound pickups and electrocardiographic leads in their tips, as well as double-lumen and balloon catheters, are available for special studies

The care of catheters is of utmost importance in the prevention of pyrogenic reactions. Upon completion of the study, the catheters should be rinsed for twenty-four hours with tap water and then allowed to soak for twenty-four hours in 500 ml. of distilled water containing 3 ml. of Detergicide. The catheters are next washed with 30 ml. of a 3 per cent solution of hydrogen peroxide and finally rinsed with distilled water. Sterilization is carried out by autoclaving the catheters for fifteen minutes in cellophane tubes under 20 lbs. of pressure at 250° F., or by placing the catheters in hot formaldehyde vapors.

TECHNIQUE OF RIGHT-SIDED CARDIAC CATHETERIZATION

In adults and in children over the age of four years, the basilic vein or one of its tributaries in the antecubital fossa is ordinarily selected as the site for insertion of the catheter. The cephalic vein is rarely used because passage of the catheter is hindered by the acute angle formed at its junction with the axillary vein. The right arm is usually chosen for the following reasons: (1) ease in manipulation of the catheter, (2) a slightly shorter distance from the point of entry of the catheter to the chambers of the right side of the heart, (3) avoidance of a left superior vena cava which, when present, ordinarily empties into the coronary vein, making catheterization of the right ventricle and pulmonary artery almost impossible, and (4) greater ease in utilizing the loop technique (see below) for passage of the catheter through the tricuspid valve into the right ventricle and then into the pulmonary artery.

The small size of the antecubital veins in infants usually prevents their use for catheterization. Ordinarily, therefore, the catheter is inserted into the saphenous or superficial femoral vein. This approach facilitates the passage of a catheter into the left atrium through an atrial septal defect or a patent foramen ovale. It is somewhat more difficult, however, to pass the catheter from these veins in the lower part of the body into the pulmonary artery than from one of the veins in the arm. Rarely is it necessary to use the common femoral or axillary vein as a point of entry for the catheter.

The area overlying the vein chosen for catheterization is thoroughly cleaned with antiseptic solution and sterilely draped. When an antecubital vein is to be exposed, a tourniquet placed around the upper arm aids in the

dissection. The skin over the vein and the subcutaneous tissues surrounding the vein are anesthetized with ample amounts of 1 per cent procaine solution and the skin is incised. By blunt dissection, a 2- to 3-cm. length of vein is freed from the surrounding tissues and lifted into the opening of the wound with a curved hemostat or an aneurysm needle. The distal end of the vein is ligated and a ligature is looped loosely around the vein's proximal end, the proximal ligature being held by a hemostat. A catheter suitable in size to the vein is selected and attached by a three-way stopcock to the tubing of a reservoir which contains 1000 cc. of physiologic saline solution with 10 to 20 mg. of heparin. The reservoir should be hung approximately 5 to 6 feet above the subject so that a slow drip may be maintained through the catheter at all times, even when the tip enters a high-pressure area. If blood enters the catheter and leads to the formation of a clot in the catheter's lumen, the catheter should be removed, rather than an attempt made to wash out the clot with fluid under pressure. The catheter, once connected to the reservoir, is flushed with saline solution until free of air bubbles. The vein is incised, the catheter inserted and advanced immediately so that its tip lies in the thorax. Following completion of the study and removal of the catheter, the proximal end of the vein is ligated, the wound edges drawn together with an adhesive butterfly, and the arm firmly bandaged.

In infants and children up to the age of four years, exposure of the saphenous or superficial femoral vein is a somewhat more extensive procedure than exposure of an antecubital vein. It is carried out in essentially the same manner. The dissection should not only delineate the venous system in the groin, but should also define the femoral artery for purposes of orientation and for its subsequent use in obtaining arterial blood samples If, as rarely occurs, it is necessary to use the common femoral vein, the wall of the vein should be repaired following removal of the catheter. At the end of the study, the dead space is obliterated, the skin edges drawn together with interrupted silk sutures and the groin firmly bandaged.

Once the catheter has been inserted into the vein, monitoring of the electrocardiogram begins and is maintained until the study is finished.

Under fluoroscopic guidance the catheter is advanced into the right atrium (Fig. 1). Difficulty may be encountered in passing the catheter from the arm into the thorax. Ordinarily the catheter can be advanced past the point of obstruction by having the subject inspire deeply, the catheter being pushed forward during the inspiratory effort Occasionally, abduction of the entire arm or positioning of the head to the right or left will help in advancing the catheter into the thorax.

When the catheter tip has reached the right atrium, it is directed medially toward the right ventricle and advanced (Fig. 2). Quite frequently, especially when the catheter has been inserted in the left arm, the catheter tip will pass into the right ventricle (Fig. 3) and may then be pushed forward into the pulmonary artery (Figs. 4 and 5). Should this maneuver fail, the catheter tip is directed toward the outer (right) wall of the right atrium. As it is pushed forward, an incomplete loop will be formed by the distal 10 cm. Twisting of the catheter will cause the loop to rotate medially, the tip of the catheter passing into the right ventricle and pointing toward the

pulmonary valve. *The catheter is then easily advanced into the pulmonary* artery. Once the pulmonary artery has been entered, the catheter tip is directed into the right (Fig. 6) or left branch (Fig. 7) and advanced until it becomes wedged in one of the smaller pulmonary vessels. Wedging of the catheter tip is most successfully accomplished when the subject inspires deeply.

TECHNIQUE OF LEFT-SIDED CARDIAC CATHETERIZATION

During catheterization of the right side of the heart, the catheter often passes through an atrial septal defect or a patent foramen ovale into the chambers of the left side of the heart. Occasionally catheters have been in-



Fig. 1



Fig. 2



Fig 3



Fig 4

Figures 1-7 Normal course taken by a catheter during its passage into the pulmonary artery 1, Right atrium 2, Tricuspid valve. 3, Mid right ventricle 4, Pulmonary artery (Continued on opposite page)



Fig 5



Fig 6



Fig. 7

Figures 1-7 (continued from opposite page) 5, Pulmonary artery. 6, Right pulmonary artery. 7, Left pulmonary artery.

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serted into the left ventricle in a retrograde manner from the aorta. All other methods of left-sided cardiac catheterization involve needle puncture of the left atrium or the left ventricle.

Four different methods of cardiac puncture have been used:

1. Transbronchial left atrial puncture. With the patient under local anesthesia the carina of the trachea is visualized bronchoscopically. A suitable-sized needle, attached to an aspirating tube 50 cm. in length, is introduced into the bronchoscope, and advanced through the anterior wall of the left main bronchus near its junction with the trachea, and then into the left atrium, which lies 3 to 5 cm. below the bronchus. The procedure should not be performed in the presence of pulmonary infection.

2. Transthoracic paravertebral puncture of the left atrium. Left atrial puncture is performed with the patient in the prone or left lateral decubitus position. Prior to the procedure, the position of the left atrium in the thoracic cage is ascertained fluoroscopically or from x-ray films, the seventh and ninth ribs being identified by markers placed on the patient's back 5 cm. to the right of the spinous processes. With the patient suitably positioned on the fluoroscopic table the markers are removed, the skin cleaned with antiseptic solution and the area sterilely draped. The underside of the fluoroscopic screen is covered with a sterile towel. The site chosen for puncture usually lies in the seventh or eighth intercostal space 4.5 to 7 cm. to the right of the vertebra (to the left of the vertebra if the aorta descends on the right), at a point judged to be closest to the center of the left atrium.

Following infiltration of the skin and subcutaneous tissues with a 1 per cent solution of procaine, a 20-cm. thin-walled No. 18 needle filled with fluid and attached to a syringe is passed through the skin and angled obliquely 25 degrees to the left so that it passes the body of the vertebra Once past the vertebral body, negative pressure is applied to the syringe and the needle is advanced into the left atrium. Increased resistance is usually encountered as the left atrium is reached and pulsation may be felt through the needle unless atrial fibrillation is present. Puncture of the atrial wall is accomplished with a short sharp push, and is immediately followed by a rapid flow of bright-red blood into the barrel of the syringe

3. Transthoracic left ventricular puncture. With the patient in the supine position, the location of the apex beat and the second right costochondral junction are marked on the skin. The skin of the anterior of the chest is then cleansed and sterilely draped. At a point 2 cm. below and lateral to the apex beat, the skin and subcutaneous tissues down to the pericardium are infiltrated with procaine. The occurrence of extrasystoles during infiltration of the subcutaneous tissues usually indicates penetration of the myocardium with the tip of the needle. Care should be taken to avoid infiltrating the myocardium with procaine, since this occurrence may be associated with the development of an arrhythmia. A No. 18 thin-walled needle filled with fluid is then inserted at the apex and directed toward the right second costochondral junction with a backward inclination of approximately 35 degrees. A sense of resistance is encountered when the

needle penetrates the myocardial wall just prior to entering the left ventricular cavity.

4. Suprasternal left atrial puncture. With the patient in the supine position and the head slightly extended and turned to the left, the neck and suprasternal region are prepared and draped in a routine manner Two to three centimeters above the suprasternal notch, the skin and the subcutaneous tissues anterior to the trachea and down to the aortic arch are infiltrated with a solution of 1 per cent procaine A long, thin 20-gauge needle is then inserted through the skin and directed anteriorly along the trachea to the aorta, whose pulsations may be readily felt through the needle. The needle is then inclined backwards and advanced behind the aortic arch into the left atrium, which lies 8 to 16 cm. below the upper border of the sternum Alternatively the needle may be advanced through the aorta, the pulmonary artery and finally into the left atrium.

5. Trans-septal left atrial puncture A No 9 Lehman catheter 60 cm. long with a removable adapter is inserted into the saphenous vein and advanced into the right atrium. A special thin-walled needle, 61 5 cm. in length, with its distal 7 cm. curved, is then inserted into the catheter so that the needle extends to the end of the catheter, but not beyond. With the needle in place and the catheter tip pointed medially and slightly posteriorly, the catheter is advanced so that its tip comes to lie against the atrial septum. The needle is then advanced 15 mm. through the septum into the left atrial chamber.

In all methods of puncture of the left side of the heart, small plastic or nylon catheters may be inserted through the needle into the cardiac chamber for the purpose of recording pressures or the injection of indicator substances. A catheter introduced into the left atrium through a needle can usually be passed into the left ventricle and often into the aorta. By continuously recording pressure pulse curves while the catheter is withdrawn from the aorta to the left atrium, the pressure gradients across the aortic and mitral valves may be measured. Retrograde catheterization of the ascending aorta with small plastic catheters inserted percutaneously into the femoral artery through No. 19-gauge thin-walled needles has been combined with any one of the several methods of recording left atrial and left ventricular pressures. In one technique, left atrial and left ventricular pressures are recorded simultaneously following separate punctures of the two cardiac chambers. In another technique, atrial and ventricular pressures are recorded simultaneously through two catheters, inserted through one needle, into the left side of the heart following left atrial puncture. Alternatively, ventricular pressures may be recorded through a catheter inserted into the left atrium and advanced into the left ventricle, while left atrial pressures are recorded directly from the needle itself.

At all times care is taken to avoid the entrance of air into the catheter and to prevent clotting in the needle's or catheter's lumen. The electrocardiogram is continually watched for the development of an arrhythmia.

COMPLICATIONS

The most common complication of cardiac catheterization is the occurrence of an arrhythmia. Indeed, it is unusual to catheterize the heart without the development of some ectopic beats. The arrhythmias occur most frequently as the catheter is moved through the heart (especially in the region of the atrioventricular valves and within the ventricles) while blood samples are drawn or during the injection of contrast media into a chamber. The most important single factor in the prevention of serious rhythm disturbances is continuous electrocardiographic monitoring during the procedure. The onset of any disturbance in rhythm is then quickly appreciated and will usually subside when the catheter tip is moved.

Many types of arrhythmias have been reported. Atrial, nodal and ventricular extrasystoles occur quite frequently and ventricular tachycardia occurring in short bursts is not uncommon as the catheter tip is moved in the region of the ventricular septum. Paroxysmal atrial tachycardia, atrial flutter and atrial fibrillation occur less frequently. Heart block of various degrees and right bundle branch block may develop. Fortunately, ventricular fibrillation is uncommon.

Endocardial trauma is a potential complication but has been reported infrequently. Persistence of a right bundle branch block following removal of the catheter from the heart may be an indication of endocardial damage in the outflow tract of the right ventricle. Instances have been recorded in which the catheter has been passed into the pericardial cavity, presumably through the wall of a cardiac vein.

Serious neurological complications have occurred as a result of air bubbles entering the catheter system. Pulmonary infarction may occur with prolonged wedging of the catheter in a small pulmonary vessel or as a result of a loosened thrombus in the venous circulation.

Local irritation and thrombophlebitis at the entrance site of the catheter occur with moderate frequency. The severity of the reaction is related to the selection of a proper sized catheter, the use of adequate local anesthesia and the amount of manipulation of the catheter during the study. The occurrence of venospasm is troublesome both to the patient and the physician, and on occasion has been of such severity as to necessitate surgical removal of the catheter. Venospasm can ordinarily be controlled by adequate infiltration of procaine into the area surrounding the insertion site of the catheter and by assuring the general comfort of the patient.

Syncopal episodes associated with dilated pupils, facial pallor, perspiration and a marked bradycardia may occur at any time during right- or left-sided cardiac catheterization, but are somewhat more frequent when the latter procedure is carried out with the patient in the left lateral decubitus position. Persistence of the episode necessitates treatment with vasopressor agents.

In patients with severe pulmonary stenosis, passage of the catheter into the pulmonary artery may lead to hypotension or a marked increase in cyanosis when a right to left shunt is present. The catheter should be withdrawn immediately under these circumstances.

Pyrogenic reactions have decreased in frequency with better techniques of catheter care. *In severely ill patients, these reactions may result* in death.

Occasionally a catheter has become knotted in the right side of the heart and in one instance, two catheters became knotted in the left atrium. This unusual complication may be avoided during right-sided cardiac catheterization by guarding against excessive looping of the catheter in the cardiac chambers. The formation of a knot in a catheter usually necessitates thoracotomy for its removal.

Catheterization of the left side of the heart is associated with many of the complications of right-sided cardiac catheterization as well as others resulting from cardiac puncture. Bleeding into the pericardium is a common occurrence. It is usually slight, but occasionally may be massive, causing cardiac tamponade and necessitating pericardial aspiration. Hemothorax and pneumothorax may also occur, the latter complication being most common when cardiac puncture is carried out by the transthoracic route. Because of these complications it is customary to x-ray the patient's chest upon completion of the procedure and again twenty-four hours later.

The mortality from right-sided cardiac catheterization is low, nine deaths being directly attributed to the procedure during 11,550 studies carried out in this country and in Sweden. Similar figures have not been collected for left-sided cardiac catheterization, but it is probable that the mortality is somewhat higher. The addition of selective angiocardiography to cardiac catheterization increases the risk of the study slightly.

STUDIES

Catheterization of the heart makes possible two types of cardiac evaluation: (1) a physiologic evaluation based on the chemical analysis of blood samples and the study of pressures and indicator dilution curves, and (2) an anatomic evaluation based on observation of the catheter's course and study of the opacification of the heart and great vessels by selective angiocardiographic techniques

Blood Samples: Samples of blood drawn through the catheter are most often analyzed for their oxygen content and saturation The oxygen content of a blood sample is expressed in volume per cent or ml./liter, and represents the amount of oxygen carried by 100 and 1000 ml. of blood respectively. The oxygen saturation of the blood is the relationship, expressed as a percentage, of the measured oxygen content of a blood sample to the amount of oxygen that the sample would contain were it exposed to room air under normal atmospheric conditions.

The oxygen content of a blood sample may be determined manometrically by the method of Van Slyke and Peters on a 5-ml. sample of blood drawn into a heparinized syringe which is capped with mercury. The sample is then stored in a refrigerator until the analysis is performed. Alternatively the blood sample may be evacuated under oil from the syringe to a small glass container. The manometric estimations should

be carried out in duplicate with a maximal difference of 0.2 vol. per cent being permitted between the two determinations.

Rapid photometric determinations of the oxygen saturation of red cells may be carried out on smaller blood samples by means of a cuvette oximeter. Multiple estimations of oxygen saturation may be made in each of the cardiac chambers, thereby increasing the accuracy of a diagnostic study. In addition, knowledge of results while the catheterization is in progress permits the physician to alter the design of the study so that the cardiac abnormality present may be delineated more clearly.

When drawing a blood sample, either into a syringe or over the photoelectric cells of an oximeter, the dead space of the catheter must first be evacuated before a representative sample can be obtained. During sampling, the electrocardiogram should be watched closely since suction applied to the catheter may result in ectopic rhythms when the catheter tip lies next to the myocardial wall. Care must also be taken to prevent the entrance of air into the catheter system during the withdrawal of blood, since an air embolus may be disastrous in patients with defects between the right and left sides of their hearts. Once the blood sample has been obtained, fluid is washed through the catheter in order to prevent clotting within the catheter's lumen.

General Consideration of Oxygen Studies: The laminar nature of venous blood flow leads to poor mixing of blood within the venae cavae and results in moderate differences in the oxygen content or saturation of blood samples derived from different areas of these vessels. Variability in the oxygenation of blood samples is most marked in the inferior vena cava where samples of blood taken from opposite sides of the vessel may differ by as much as 2 vol. per cent. Blood flows into the right atrium from the two venae cavae and the coronary sinus, each vessel draining a different segment of the body and each therefore having a different oxygen content or saturation. Ordinarily the oxygenation of blood in the inferior vena cava is slightly greater than that in the superior vena cava and much greater than that of blood in the coronary sinus. Within the right atrium the mixing of blood derived from these three sources is incomplete and leads to some variation in the oxygen content or saturation of samples drawn from various parts of this chamber. Usually the average oxygen content or saturation of vena caval blood is slightly higher than the average content or saturation of multiple samples obtained in the right atrium. Because of better mixing within the right ventricle, less marked variations in oxygenation of the venous blood are found in this chamber. Blood samples drawn from the pulmonary artery vary least of all in their oxygenation and are considered to be representative of the body's mixed venous blood.

Certain types of cardiac malformations cause the admixture of highly oxygenated blood from the pulmonary veins, the aorta or the chambers of the left side of the heart with the less oxygenated blood of the right side of the heart. The presence of such a defect and its location may be established by noting the site at which a significant increase in the oxygenation of venous blood occurs. An increase in venous oxygenation

significant of a left to right shunt must be greater than the variations in oxygen content or saturation occurring under normal conditions between blood samples drawn from the venae cavae, right atrium, right ventricle or pulmonary artery. Normally the differences in venous oxygenation are greatest between caval and right atrial samples and least between right ventricular and pulmonary arterial samples. The significance of an increase in oxygen content may be altered by the level of the subject's hemoglobin, comparable shunts producing smaller increases in oxygen content at lower hemoglobin levels than at higher ones. Shunts of similar size may also result in varied increases in oxygen saturation, greater increases in saturation occurring when shunted blood mixes with venous blood of lower saturation rather than higher saturation. These considerations assume importance in the study of anemic or polycythemic patients or in infants during the neonatal period when marked changes in hemoglobin occur. By obtaining multiple blood samples during the catheterization the significance of a measured rise in oxygenation may be more readily determined.

Significance of Oxygen Studies: In normal resting subjects, blood in the venae cavae and right atrium has an oxygen saturation of 70 to 80 per cent. The finding, in either of the venae cavae or right atrium, of a 10 per cent increase in oxygen saturation or a rise in oxygen content of 1.9 vol. per cent over that of a blood sample derived from one or both of the other sites is indicative of a left-to-right shunt. Increases of 5 per cent in oxygen saturation or 1 vol per cent in oxygen content may be considered significant of a left-to-right shunt when the measured increase represents an average value derived from three or more samples obtained from each of the sites being compared.

Ordinarily it is not possible to define exactly the type of defect present on the basis of the oxygen data alone, since five different abnormalities may produce significant increases in oxygenation of blood in the right atrium and venae cavae: (1) atrioseptal defect, (2) anomalous pulmonary venous drainage into the venae cavae or right atrium, (3) a communication between the sinus of Valsalva and the right atrium, (4) a communication between the aorta and right atrium, through an anomalous coronary artery, and (5) a ventricular septal defect associated with tricuspid insufficiency. Further delineation of the abnormality is accomplished by locating the defect with the catheter, or by means of angiocardiographic or dilution studies.

An admixture of venous and arterial blood within the right ventricle may be considered present when a right ventricular blood sample shows an increase of 7 per cent in oxygen saturation or a rise of 1.4 vol. per cent in oxygen content over that of a sample obtained from the right atrium. A comparison of the average values of three or more samples in both the ventricle and the atrium showing an increase of 3 per cent in oxygen saturation, or 0 5 vol. per cent in oxygen content of right ventricular blood over right atrial blood is also indicative of an admixture of arterial and venous blood within the right ventricular cavity.

Four types of abnormalities are associated with a significant increase in oxygenation of venous blood in the right ventricle: (1) ventricular septal defect, (2) a communication between the sinus of Valsalva and the right ventricle, (3) patent ductus arteriosus with pulmonic insufficiency, and (4) atrial septal defect. In each instance the abnormalities may be differentiated each from the other by means of angiocardiographic and dye dilution studies or by passage of the catheter into the defect.

Significant increases in pulmonary arterial blood oxygenation over that of right ventricular blood may be found with four types of abnormalities: (1) patent ductus arteriosus, (2) a communication between the root of the aorta and the pulmonary artery, (3) a ventricular septal defect, and (4) overriding of the pulmonary artery. When single samples of right ventricular and pulmonary arterial blood are compared, increases of 5 per cent in saturation or 1 vol. per cent in oxygen content are considered significant, whereas increases of 3 per cent in oxygen saturation or 0 5 vol. per cent in oxygent content are considered significant if the average values of three or more samples from the pulmonary artery and right ventricle are compared. Further delineation of the abnormality may be obtained from additional studies by angiocardiographic or dilution techniques.

The normal arterial oxygen saturation is 95 per cent. Levels below normal are indicative of a right-to-left shunt or of incomplete oxygenation of the blood within the lungs. The inhalation of 100 per cent oxygen for twenty minutes leads to complete saturation of arterial blood, when arterial unsaturation is due to inadequate oxygenation of the venous blood in the lungs, except in the presence of a pulmonary arteriovenous aneurysm. In the presence of an intracardiac or intrapulmonary shunt the arterial blood fails to become fully saturated even though 100 per cent oxygen is breathed by the patient for periods of twenty minutes or more.

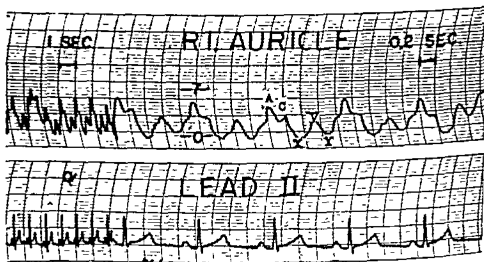


FIGURE 8. Normal right atrial pulse pressure curve taken simultaneously with Lead II of the electrocardiogram.

Pressure Measurements: The determination of pressures and the recording of pulse pressure curves are essential to any complete physiologic evaluation of the cardiovascular system. In addition, the distinctive characteristics of pulse pressure curves are useful in locating the position of the catheter tip during its passage through the heart.

All manometric determinations are related to a fixed point on the subject's body. With the subject reclining on his back the midthoracic line, the anterior axillary line, the sternal angle, or a point 10 cm above the subject's back have been used as points of reference In this section all pressures are related to the subject's midthoracic line.

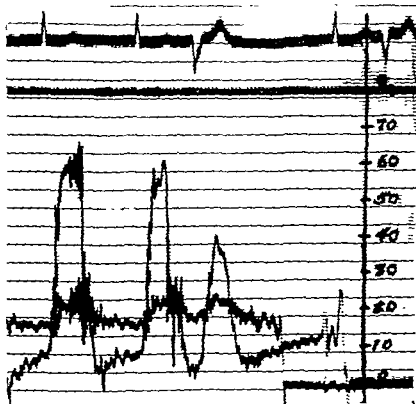


FIGURE 9 Simultaneous right atrial and right ventricular pressure pulse curves in a patient with tricuspid stenosis The right atrial diastolic pressure is elevated above right ventricular diastolic pressure

Right Atrial Pressure: Normal values for mean right atrial pressure range from 0 to 5 mm. of Hg in adults and children and from 0 to 3 mm. of Hg in newborn infants. The normal right atrial curve (Fig. 8) has three distinctive positive deflections, A, C, V, and two marked troughs, X and Y. The A wave is associated with atrial systole and ranges from 3 to 7 mm. of Hg at its peak It disappears in atrial fibrillation and is usually large in severe pulmonary stenosis, tricuspid stenosis and severe pulmonary hypertension, provided there is no free communication between the left and right atria



FIGURE 10 Right atrial pressure pulse curve recorded simultaneously with the electrocardiogram in a patient with constrictive pericarditis The atrial pressure is elevated above normal and the curves have an M-shaped configuration.

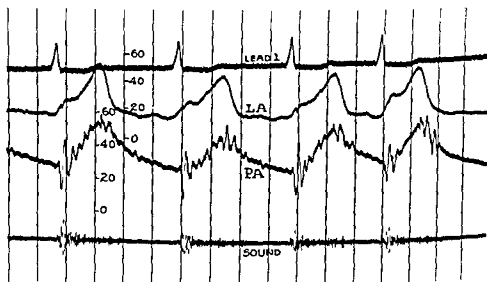


FIGURE ... arterial
and left
The left
rapid Y
in millimeters of mercury.

The C wave is usually no more than 1 mm. in height, and occurs during the time atrial pressure is dropping to the X trough. Its mechanism of production is not as yet clearly understood. The V wave occurs in association with atrial filling during ventricular systole and reaches a peak ranging from 2 to 7 mm. of Hg just prior to tricuspid opening. The Y trough occurs in diastole at the end of the rapid phase of ventricular

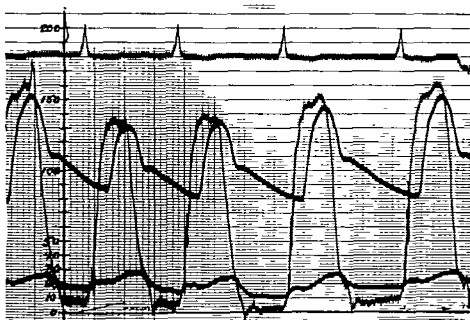


FIGURE 12 Pressure pulse curves recorded simultaneously from the left atrium, the left ventricle and the brachial artery in a patient with mitral stenosis The left atrial pressure is increased above left ventricular pressure during diastole Brachial arterial and left ventricular systolic pressure are approximately equal

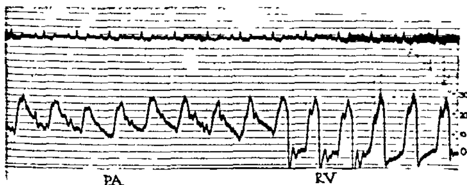


FIGURE 13 Normal pressure pulse curves recorded as the catheter is withdrawn from the pulmonary artery to the right ventricle

filling. In the presence of tricuspid insufficiency the Y descent is rapid, and the V wave markedly increased. When tricuspid stenosis is present the Y descent is slow, the Y trough shallow or absent and right atrial pressure is elevated above right ventricular pressure during diastole (Fig. 9). With constrictive pericarditis and other types of cardiovascular abnormalities which limit cardiac filling, such as amyloid heart disease, the right atrial pressure is elevated and the curves have an M-shaped configuration (Fig. 10).

Left Atrial Pressure: The normal configuration of the pulse pressure curve of the left atrium is quite similar to that of the right atrium, except

for increased prominence of the C wave. In normal subjects, mean left atrial pressure ranges between 3 to 7 mm. of Hg, being slightly higher than mean right atrial pressure. When a large atrial septal defect exists, the pressure differential between the two chambers is reduced. Left atrial mean pressure is elevated in the presence of mitral stenosis, mitral insufficiency or left ventricular failure. In mitral insufficiency the V wave

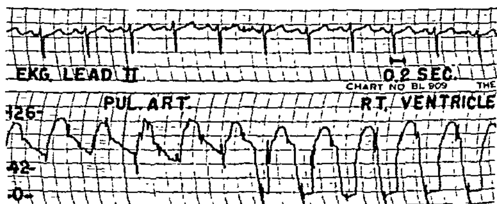


FIGURE 14 Elevated pulmonary arterial and right ventricular pressure pulse curves in a patient with Eisenmenger's complex

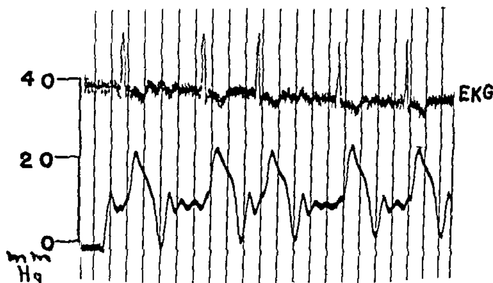


FIGURE 15 Right ventricular pulse pressure curves in a patient with constrictive pericarditis The systolic pressure is not elevated There is an early diastolic drop in pressure followed by a high end diastolic pressure.

is high and the Y descent rapid (Fig. 11). In the presence of mitral stenosis, left atrial diastolic pressure is elevated above left ventricular diastolic pressure, the Y descent is slow and the Y trough is shallow (Fig. 12).

Right Ventricular Pressures: In normal subjects, right ventricular systolic pressure ranges from 17 to 30 mm. of Hg, and the end diastolic pressure ranges from 2 to 6 mm. of Hg (Fig. 13). Right ventricular systolic pressure

may be elevated in the presence of right-sided heart failure, severe pulmonary disease or in association with a number of congenital defects (Fig. 14). Marked elevation of right ventricular end diastolic pressure in association with slight elevation of the systolic pressure is seen in constrictive pericarditis (Fig. 15). In the presence of infundibular stenosis the systolic pressure in the body of the right ventricle is greater than that in the infundibulum (Fig. 16). When valvular pulmonary stenosis exists, right

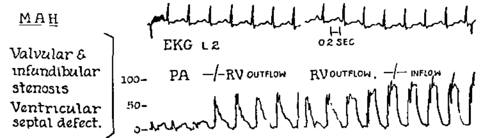


FIGURE 16 Continuous pressure recording during the withdrawal of the catheter from the pulmonary artery to the right ventricle in a patient with valvular and infundibular pulmonic stenosis

FIGURE 17. Simultaneous left ventricular and left atrial pulse pressure curves in a patient with left-sided heart failure After the second cardiac cycle, the catheter recording left ventricular pressures was withdrawn into the left atrium. The elevation of left atrial and left ventricular diastolic pressures is the only abnormality present.

ventricular systolic pressure is far greater than pulmonary systolic pressure. An increase of 10 to 20 mm. of Hg in right ventricular systolic over pulmonary systolic pressure may be found when the output of the right ventricle is markedly increased, as occurs with an atrial septal defect, and does not necessarily signify anatomic narrowing of the pulmonary orifice.

Left Ventricular Pressure: The normal pressure pulse curve of the left ventricle is comparable in configuration to that of the right ventricle.

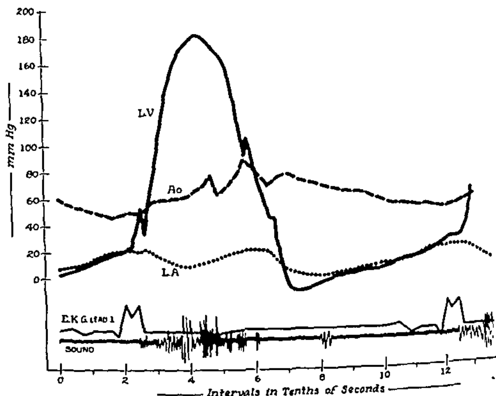


FIGURE 18 Simultaneous electrocardiogram, heart sounds, left atrial, left ventricular and aortic pressure pulse curves in a patient with aortic stenosis. Left ventricular systolic pressure is markedly elevated over aortic systolic pressure.

Normally, systolic pressure ranges from 90 to 140 mm. of Hg and end diastolic pressure ranges from 2 to 8 mm. of Hg. Left ventricular end diastolic pressure is increased with failure of the left ventricle (Fig. 17). Normally, aortic or brachial arterial systolic pressure is comparable to left ventricular systolic pressure (Fig. 12). In the presence of aortic stenosis, the systolic pressure in the aorta is markedly reduced over that in the left ventricle (Fig. 18).

Pulmonary Arterial Pressure: Normal pulmonary arterial pressures are: systolic, 14 to 29 mm. of Hg; diastolic, 4 to 12 mm. of Hg; and mean, 9 to 19 mm. of Hg (Fig. 13). They are elevated in the presence of mitral valve disease, left-sided heart failure, pulmonary disease and in association with a number of congenital defects. In the presence of valvular pulmonary stenosis, pulmonary arterial pressure may fall during systole instead of

rising as it normally does (Fig. 19), the paradoxical fall in pressure resulting from the increased velocity of blood flow through the narrowed pulmonary orifice. With pulmonary insufficiency the pulmonary diastolic pressure may approach that of the diastolic pressure in the right ventricle.

Pulmonary Wedge Pressure: Pressures recorded with the catheter wedged in a small pulmonary vessel show a configuration similar to that of left atrial pressure curves. Normal values for pulmonary wedge mean



FIGURE 19. Continuous pressure recording as a catheter is withdrawn from the pulmonary artery to the right ventricle in a patient with valvular pulmonic stenosis Right ventricular systolic pressure is markedly elevated over pulmonary arterial pressure The fall in pulmonary arterial pressure during *systole* is caused by the high velocity of blood flow just distal to the narrow pulmonary valve.

pressures range from 6 to 12 mm of Hg. This is approximately the same pressure as that found in the pulmonary veins and possibly slightly higher than left atrial mean pressure. Conditions affecting left atrial pressure alter pulmonary wedge pressure in a comparable manner. Pressure changes recorded with the catheter in the wedged position occur 0.1 seconds later than similar changes in the left atrium.

Indicator Dilution Studies: The intravenous injection of a substance that does not leave the circulation while in transit through the lungs is followed eight to ten seconds later by its appearance in arterial blood. The concentration of the injected material increases to a peak value in several seconds and then declines at a slower rate until recirculation occurs. By plotting logarithmically the changes in concentration of the indicator, the descending portion of the curve becomes a straight line which allows extrapolation of the slope. The theoretical duration of the indicator's presence at the sampling site and its average concentration during this period of time, were recirculation not to occur, may be obtained from curves constructed in this manner (Fig. 20). Estimations of flow are then made with the following formula:

$$\text{F or CO} = \frac{I \times 60}{CT}$$

where F or CO = blood flow in liters/minutes
I = amount of indicator injected in mg
C = mean concentration of indicator in sample in mg per 1000 ml.
T = duration of the time concentration curve in seconds

Ordinarily, radioactive isotopes or dyes are used as indicators. Their presence in the blood is detected by radiation counters or with photoelectric cells that measure optical density. Time concentration curves of Evans blue dye T1824 or indigo carmine may be continuously recorded by drawing blood through a cuvette whose light source has a wave length of 620 to 640 microns. The use of these two indicators is of limited value in cyanotic patients because baseline variations are associated with respir-

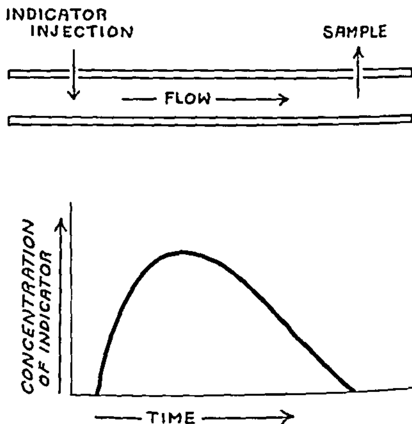


FIGURE 20 Normal dilution curve recorded from a peripheral artery following the injection of K^{42} into a peripheral vein

atory shifts in the ratio of saturated to unsaturated hemoglobin, each form of hemoglobin having a different optical density. Variations in hemoglobin saturation do not influence the measurement of iodocyanine green or Coomassie blue since the light sources utilized have a wave length of 805 or 535 to 590 microns, respectively.

Radioactive potassium is an excellent indicator substance because its rapid disappearance from the circulation makes possible multiple studies over a short period of time. Its short half-life and cost have limited its use

In the presence of a right-to-left shunt, some of the indicator by-passes the lungs and appears in the arterial blood sooner than normal Under these circumstances, time concentration curves show an early increase followed by a second increase, which represents indicator that has passed through the lungs (Fig. 21).

In the presence of a left-to-right shunt, the initial components of the time concentration curve are normal while the descending slope is distorted by early recirculation of the indicator through the vascular defect. The magnitude of the shunt is determined from the distorted portion of the descending slope (Fig. 22).

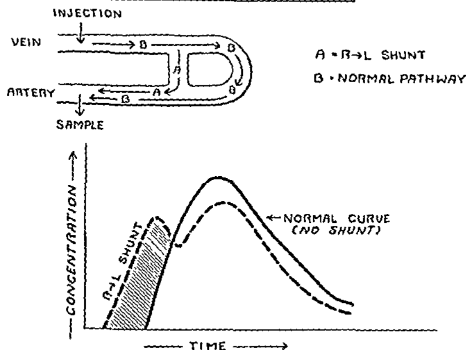


FIGURE 21 Dilution curve recorded from a peripheral artery following the injection of K^{42} into a peripheral vein in a patient with a right-to-left shunt.

By combining dilution techniques with cardiac catheterization, the indicator may be injected selectively into various areas of the heart or great vessels, thereby localizing the site of a shunt (Fig. 23).

Study of time-concentration curves following the injection of indicators into the left atrium and left ventricle during left-sided cardiac catheterization has proved useful in the diagnosis of mitral and aortic valvular disease. In the presence of mitral stenosis, injections into the left atrium may result in delayed or normal appearance time of the indicator while the form and height of the curve is unaltered. Injection into the left ventricle is associated with a normal appearance time of the injected substance. When mitral insufficiency exists, injections into the left atrium and left ventricle lead to time-concentration curves with a normal appearance time, a lower peak concentration and a decrease of the des

slope of the curve. Further evidence of the presence of mitral insufficiency may be obtained by injecting indicators into the ventricle and sampling from the left atrium (Fig. 24). Under these circumstances an immediate concentration of the injected material appears in samples drawn from the left atrium. The amount of forward flow (effective flow) and regurgitant flow may then be calculated from the following formula:

$$\frac{\text{Area under atrial curve}}{\text{Area under peripheral curve}} = \frac{\text{Regurgitant flow}}{\text{Regurgitant flow and effective flow}}$$

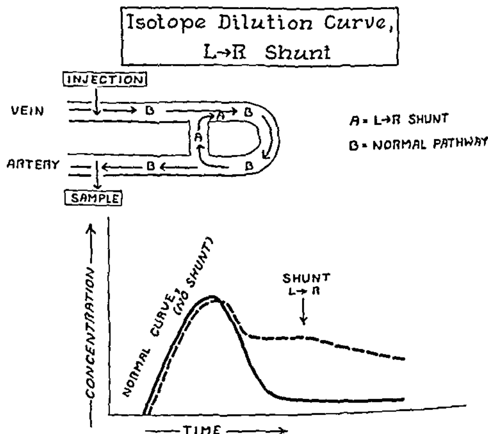


FIGURE 22. Dilution curve recorded from a peripheral artery following the injection of K^{42} into a peripheral vein in a patient with a left-to-right shunt.

In a similar manner, samples drawn from the left ventricle following injection into the root of the aorta will provide information as to the presence and magnitude of aortic insufficiency.

Catheter Course: By observing the course of the catheter as it is advanced in the thorax, or while its tip explores the walls of the cardiac chambers or the sides of the great vessels, information may be gained as to chamber size, wall thickness and the nature of certain congenital defects. When a significant increase in oxygenation of venous blood occurs within the right atrium or venae cavae, the type of defect present may be delineated by passing the catheter through a septal defect (Fig. 25), or by entering an

anomalous pulmonary vein from either of the venae cavae (Fig 26). Localization of pulmonary venous drainage by advancing the catheter into the lung field from the region of the atria may be difficult, owing to similarities in the appearance of the course taken by the catheter when it enters a pulmonary vein directly from the right atrium, or from the left atrium after having passed through an atrial septal defect (Fig. 27). Under these circumstances, regional angiocardiography and selective dilution studies will clarify the type of pulmonary venous drainage present.

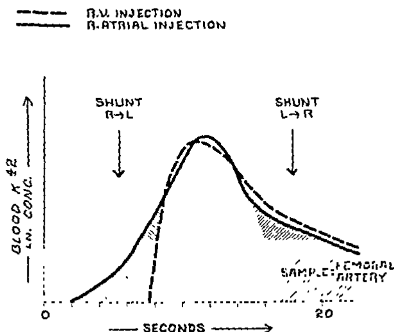


FIGURE 23 Dilution curves recorded from a peripheral artery following the injection of K^{42} into the right ventricle and right atrium of a patient with a right-to-left shunt at the atrial level Injection of the indicator into the right atrium is followed by an early appearance time in the peripheral artery

When an increase in oxygenation of venous blood occurs within the right ventricle or pulmonary artery, further elucidation of the congenital abnormality may be obtained by passage of the catheter through a ventricular septal defect into the ascending aorta (Fig. 28), or through a patent ductus arteriosus into the descending aorta (Fig. 29).

Localization of a defect with the catheter is especially useful in patients with right-to-left shunts since there may be no significant alteration in oxygenation of the venous blood. This is particularly true in patients with patent ductus arteriosus and pulmonary hypertension with equalized or reversed shunts.

Whenever the catheter follows an unusual course (Fig. 30), simultaneous studies of pressure pulse curves and blood oxygenation are of aid in elucidating the reason for the abnormal path of the catheter.

Selective Cineangiocardiography: Angiocardiography has made possible anatomic studies of the cardiac chambers and great vessels as well as physiologic studies of the flow characteristics in these structures. When contrast medium is injected through a catheter, the tip of which lies in a specific heart chamber or in a great vessel, better opacification of the area

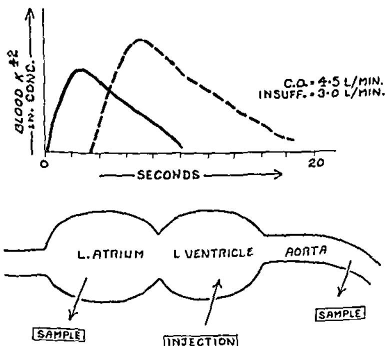


FIGURE 24 Dilution curves recorded from the left atrium and a peripheral artery following the injection of K^{42} into the left ventricle of a patient with mitral insufficiency. The indicator appears in the left atrium immediately following its introduction into the left ventricle

is obtained than when a peripheral vein serves as the site of injection. In addition, selective studies of the left side of the heart following passage of the catheter through a foramen ovale or cardiac defect may result in the demonstration of left-to-right shunts, a feat difficult to accomplish with other angiocardiographic techniques. Better interpretation of regional angiocardiograms is accomplished by photographing with motion picture cameras the opacification of a chosen area as visualized by an image intensifier.

Selective angiocardiography is best carried out at the time of routine cardiac catheterization. Information as to type and site of a cardiac abnormality is first obtained from the pressures and oxygen saturations found in the various cardiac chambers and vessels. By exploring the chamber and vessel walls with the catheter tip, further information concerning the suspected abnormality may be obtained Finally the catheter tip is positioned in such a way that the suspected defect may be delineated best by an injection of radiopaque material.



FIGURE 25 The catheter tip lies in the left atrium following its passage through an atrial septal defect

The most suitable contrast medium available at present is a 90 per cent solution of Hypaque. The material may be injected through the catheter by automatic injector or by hand with a syringe In either case the solution of Hypaque should be warmed to 100-110° F. prior to use. When injections are done by hand the injecting syringe should be dipped in boiling water before filling to prevent the formation of crystals on its cold glass walls. Regardless of the patient's size, injections of Hypaque are limited to 30 ml. In small children and infants, 0.3 to 0.5 ml./lb. of Hypaque are used, the larger dose being given in the presence of large shunts. Multiple injections of Hypaque may be given provided fifteen minutes are allowed for clearance of a major portion of the material from

the circulation. Injections appear to be equally well tolerated in the right or left cardiac chambers. Caution should be taken to avoid injections of contrast medium when the catheter tip is in a pulmonary vein, the coronary sinus, or small pulmonary arterioles. Under such circumstances the force of injections has, in some instances, torn the vessel wall. Few complications, however, have been associated with the use of Hypaque in selective angiocardiography.



FIGURE 26 The catheter tip lies in a pulmonary vein which enters the superior vena cava

Regional angiocardiography has been most beneficial in elucidating the type of a coarctation of the aorta or the nature of a pulmonary stenosis, in diagnosing a ventricular septal defect, in finding patent ductus arteriosus with reversed shunt, in locating the origin of great vessels and in delineating the abnormalities present in patients with multiple cardiac defects.

Calculations: When the oxygen uptake by the lungs is measured simultaneously with arteriovenous oxygen difference across the lungs of subjects without cardiac shunts, the output of the heart may be calculated by the Fick principle as follows:

$$Qs = \frac{VO_2}{AO_2 \text{ or } PVO_2 - PAO_2}$$

where

Qs = Cardiac output in liters/min.
VO_2 = Oxygen uptake by the lungs in ml./min
AO_2 = Arterial oxygen content in ml.
PVO_2 = Pulmonary venous oxygen content in vol %
PAO_2 = Pulmonary arterial oxygen content in vol.%

When the cardiac output is expressed in liters per minute per square meter of body surface area, it is referred to as the cardiac index. Normal values for the cardiac index range between 3.1 and 3.4 liters. Variations



FIGURE 27 The catheter tip lies in a pulmonary vein It is impossible to determine from the roentgenogram whether the catheter has entered the vein directly from the right atrium or from the left atrium following its passage through an atrial septal defect

of ±10 per cent have been found in duplicate determinations of cardiac output by the Fick technique.

Utilizing the Fick principle, blood flows and shunts may be calculated in patients with congenital cardiac abnormalities. The significance of these estimates must be considered in light of certain inherent errors associated with the use of the Fick principle in patients with congenital cardiac abnormalities. In the presence of high pulmonary flow the errors associated with the determination of the blood's oxygen content become significant as a result of the small arteriovenous oxygen difference across the lungs found under these circumstances. In addition, the oxygen content

FIGURE 28 The catheter tip lies in the innominate artery following its passage through a ventricular septal defect.

FIGURE 29 The catheter tip lies in the descending aorta following catheterization of the ductus arteriosus.



FIGURE 30. A catheter which has been passed from the left arm to the inferior vena cava via an aberrant left superior vena cava, the coronary sinus and right atrium

of pulmonary venous blood when not directly sampled is assumed to be 95 per cent—an assumption that has proved incorrect in some instances when high pulmonary flows exist. Furthermore, it is often impossible to obtain blood samples representative of true mixed venous blood when shunts exist at the atrial or ventricular level. In the presence of a left-to-right shunt, estimation of pulmonary and systemic flow and the size of the shunt may be carried out as follows:

$$Qp = \frac{VO_2}{AO_2 \text{ or } PVO_2 - PAO_2}$$

$$Qs = \frac{VO_2}{AO_2 \text{ or } PVO_2 - MVO_2}$$

where Qp = Pulmonary flow in liters/min
Qs = Systemic flow in liters/min
MVO_2 = Oxygen content of venous blood in ml. prior to its admixture with shunted blood
Qp − Qs = the size of the left-to-right shunt in liters/min

When the shunt is from right to left:

$$Qp = \frac{VO_2}{PVO_2 - PAO_2}$$

$$Qs = \frac{VO_2}{AO_2 - MVO_2}$$

and $Qs - Qp$ = the size of the right-to-left shunt in liters/min.

When the shunt is bidirectional, estimates of the size of the shunt in either direction are based on determination of the effective pulmonary flow.

$$QEP = \frac{VO_2}{PVO_2 - MVO_2}$$

where QEP = effective pulmonary flow in liters/min. or that part of the total pulmonary flow which accounts for the measured uptake of oxygen in the lungs, then

$Qp - QEP$ = the left-to-right shunt in liters/min.

and

$Qs - QEP$ = the right-to-left shunt in liters/min.

Measurements of pressures in conjunction with estimations of flows make possible calculation of resistances in the pulmonary and systemic circulations.

$$Rp = \frac{PAm = PVm}{Qp}$$

where Rp = Pulmonary resistance expressed in units
PAm = Mean pulmonary artery pressure in mm. of Hg
Qp = Pulmonary flow in liters/min.
PVm = Pulmonary capillary or pulmonary vein mean pressure

Alternatively, pulmonary resistance may be expressed as dyne seconds/cm.[5] from the following equation:

$$Rp = \frac{PAm - PVm \times 981 \times 1.36 \times 60}{Qp}$$

where Qp = Pulmonary flow in ml /min.

Similarly, systemic resistance, Rs, is expressed in units:

$$Rs = \frac{BAm - RAm}{Qs}$$

where BAm = Brachial arterial mean pressure in mm of Hg
RAm = Right atrial mean pressure in mm. of Hg
Qs = Systemic flow in liters/min.

or as dyne seconds/cm.[5]:

$$Rs = \frac{BAm - RAm \times 981 \times 1.36 \times 60}{Qs}$$

where Qs = Systemic flow in ml./mins.

Pulmonary resistance in adults normally ranges between 1 and 3 units or 100 and 250 dynes/seconds/cm.[5] In children, higher values for pulmonary resistance are normally found. When pulmonary resistance is calculated on the basis of flows related to the subject's body surface area, comparable values are found in children and adults.

Utilizing pressure and flow data, calculations of right ventricular and left ventricular stroke work are carried out as follows:

$$SWI_{rv} = \frac{(PAm - \begin{matrix} RAm \\ \text{or} \\ RVd \end{matrix}) \times SI \times 1.36 \times 1\,055}{100}$$

$$SWI_{LV} = \frac{\left(\begin{matrix}BAm\\ or\\ AM\end{matrix} - \begin{matrix}LAm\\ or\\ LVd\end{matrix}\right) \times SI \times 1.36 \times 1.055}{100}$$

where SWI_{RV} = Right ventricular stroke work index in Gm M./M² Beat
SWI_{LV} = Left ventricular stroke work index in Gm M./M² Beat
BAm = Brachial arterial mean pressure in mm. of Hg
PAm = Pulmonary arterial mean pressure in mm. of Hg
RAm = Right atrial mean pressure in mm. of Hg
LAm = Left atrial mean pressure in mm of Hg
Am = Aortic mean pressure in mm of Hg
RVd and LVd = Right and left ventricular endiastolic pressure respectively, in mm. of Hg
SI = Stroke index in ml./beat/square meter of body surface
1.36 = Conversion factor from mm of Hg to cm H_2O
1.055 = Specific gravity of blood

In the presence of aortic and pulmonic stenosis, left and right ventricular work is calculated on the basis of the mean left and right ventricular systolic pressures instead of the mean brachial, aortic and pulmonary arterial pressures.

In the presence of predominant stenosis of the atrioventricular and semilunar valves, the cross-sectional valvular area may be calculated as follows:

$$MVA = \frac{MVF}{31\sqrt{Pcm \text{ or } LAdm - LVdm}}$$

$$AVA = \frac{AVF}{44.5\sqrt{LVsm - BAsm \text{ or } Asm}}$$

$$TVA = \frac{TVF}{44.5\sqrt{RAdm - RVdm}}$$

$$PVA = \frac{PVF}{44.5\sqrt{RVsm - PAsm}}$$

where MVA, AVA, TVA and PVA = the mitral, aortic, tricuspid and pulmonary valves' cross section area in cm² MVF, AVF, TVF and PVF = the mitral, aortic, tricuspid and pulmonary valve flows in ml./diastolic sec

PCm = Pulmonary capillary pressure in mm. of Hg.
LAdm and RAdm = Left atrial and right atrial mean diastolic pressure in mm. of Hg
LVdm and RVdm = Left and right ventricular mean diastolic pressures in mm. of Hg (calculated from the time of closure of the atrioventricular valves)
LVsm, RVsm, PAsm, BAsm and Asm = Left ventricular, right ventricular, pulmonary arterial, brachial and aortic mean systolic pressure in mm. of Hg

In the presence of valvular insufficiency, determination of the size of the regurgitant flow by indicator dilution techniques permits the calculation of the cross-sectional area of the valve during the period of regurgitation as follows:

$$MVRA = \frac{MVRF}{31\sqrt{LVsm - LAsm}}$$

where MVRA = Mitral valve regurgitant flow area in cm²
MVRF = Mitral valve regurgitant flow in ml /sec.
LVsm = Left ventricular systolic mean pressure in mm. of Hg from the onset of ventricular systole until the opening of the mitral valve
LAsm = Left atrial systolic mean pressure in mm of Hg

REFERENCES

Cournand, A , Baldwin, J. S., and Himmelstein, A.: Cardiac Catheterization in Congenital Heart Disease. The Commonwealth Fund, New York, 1949

Rudolph, A. M., and Cayler, G. G.: Cardiac Catheterization in Infants and Children. Pediatric Clin. North America 5:907-943, 1958.

Sones, Jr., F M.: Cine-Cardio-Angiography. Pediatric Clin. North America 5:945-979, 1958.

Symposia on Cardiac Catheterization, 1, 2 & 3. Proc. Staff Meet, Mayo Clin 23.481-521, 1948; 25:41-79, 1950; 28:49-113, 1953.

Wood, Paul: Diseases of the Heart and Circulation, 2nd Ed. J. B Lippincott Company, Philadelphia, 1956.

Zimmerman, H. A : Intravascular Catheterization. Charles C Thomas, Springfield, Ill , 1959

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The Heart in Diphtheria and Infectious Diseases Other Than Rheumatic Fever

The etiology of so many cases of heart disease falls within the rheumatic, hypertensive, or arteriosclerotic group that we at times are unmindful of the other causes of heart disease. It is perfectly true that, with the control of infection by immunological and chemotherapeutic measures, we have significantly reduced the number of instances of infectious heart disease. However, enough cases of infectious heart disease remain to merit our interest. The cardiovascular system, like other organs, is well integrated into the whole, and whatever affects the human organism, either from within or without, may be manifested in the cardiovascular system in one way or another.

DIPHTHERIA

Happily, diphtheria is now well controlled by prophylactic measures and by the administration of antitoxin or antibiotics in instances of such infection so that little or no diphtheritic heart disease now occurs During World War II doctors serving in the Pacific area were again made aware of the effects of diphtheria on the heart when numerous instances of heart block were found among personnel suffering from diphtheritic ulcers of the skin.[1] The diphtheria bacillus is rarely found in the heart, although a case of diphtheria endocarditis at the Valley Forge General Hospital was brought to our attention by Colonel Willis, Chief of the Medical Service (personal communication 1949). On three occasions this young soldier was found to have a positive blood stream infection caused by the diphtheria bacillus His death was caused finally by this infection which remained uncontrolled, producing an ulcerative endocarditis and marked cardiac enlargement. A similar case was reported by Sutherland[2] in 1936.

The necrosis and hemorrhage seen within the myocardium of patients dying with acute diphtheria is due to the toxin elaborated by this organism, rather than the organism itself (see Fig. 1). Many of the deaths due to diphtheria are probably caused by this particular effect of the toxin upon the myocardium. The question or possibility of permanent damage to the myocardium was discussed for many years. Observations were made by many clinicians.[4] We now know that survival from the diphtheritic infection usu-

ally results in complete recovery without sequelae. Jones and White[3] reported a follow-up of 100 patients studied five to eight years following well-established cases of diphtheria, and found them without any residual evidence of heart disease. In rare instances, disturbances in conduction do occur as sequelae. We have recently seen the daughter of a physician who had been carefully followed by her father since being affected by acute diphtheria at age three. Now, forty years later, she has a well-established nodal rhythm with complete auricular standstill. In the absence of any other etiological possibilities, it has been concluded that the diphtheria of forty

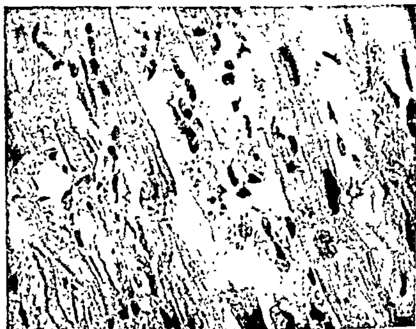


FIGURE 1 Photomicrograph showing acute diphtheritic myocarditis The degeneration and necrosis of the muscle cells are evident—"perimysial tubes containing detritus and formative cells" (From Warthin: J Infect Dis, 1942)

years ago is responsible for this mechanism (personal communication, Dr. Cordonna). Another example of a cardiac conduction disturbance has recently been brought to our attention (personal communication, Dr. H. B. Williams). A routine electrocardiogram done on a student with no cardiovascular or respiratory symptoms revealed a severe bundle-branch block. Further questioning disclosed a past history of an overwhelming diphtheria infection as a child. Since there was no history of any other significant illnesses, this case of an intraventricular conduction delay has been thought to be due to the near fatal attack of diphtheria in childhood.

There are no particular symptoms which give one the clue to diphtheritic myocardial involvement. Such symptoms as weight loss, fatigue, breathlessness, and palpitation with effort are nonspecific. They apply as much to the postinfectious asthenia and neurocirculatory asthenia as they do to any specific cardiac disorder. If the child having received antitoxin should develop a serum-sickness reaction on the tenth to fourteenth day

after receiving the serum, it might be difficult to distinguish such a reaction from a concomitant rheumatic fever. Such a reaction might also be sufficient to precipitate congestive failure in a child with postdiphtheritic myocarditis. It is well for all clinicians to be aware of this complicating myocarditis and to look for it after the infection and fever have subsided. The electrocardiogram is most useful in making a diagnosis of auriculoventricular block or intraventricular block of the bundle-branch type, or a diagnosis of other manifestations of myocarditis, long before these phenomena give clinical evidence of their existence. As the myocardial involvement progresses, signs may be evident in the way of enlargement of the heart to the right and to the left with dilatation of the mitral ring and relative mitral insufficiency, and possibly gallop rhythm may also be present as the result of the dilatation and weakness of the ventricular muscle.

The diphtheria bacillus is very sensitive to antibiotics such as penicillin, but usually we are not so concerned with the actual infection as with the toxin which is responsible for the diphtheritic myocarditis. For this reason, it is very important that large amounts of antitoxin be administered as early in the course of the disease as possible It is much too late and probably useless, if not possibly harmful, after signs of myocarditis develop A dose of 100,000 units of antitoxin is frequently given. The involvement of the heart is very insidious and often fatal and, for this reason, the patient convalescing from diphtheria should be kept at bed rest for some time until one can safely feel that all danger from this complication is past.

TRYPANOSOMIASIS

The trypanosoma cruzi invades the myocardium and is often seen microscopically in its Leishmanial forms between the myocardial fibers There is an associated inflammatory reaction and death may result from cardiac dilatation and congestive failure.

The disease so far is limited to South America and especially Brazil where it was first described by Dr. Chagas[11] in 1909. The host is the anteater. It is conveyed to man by ticks, mites, bed bugs, etc

Several American citizens on duty in Panama Canal Zone were afflicted The microphotograph (Fig. 2) is a section of the myocardium showing the Leishmanial forms and the inflammatory reaction. The trypanosomes as such are only found in the peripheral blood.

VIRUS DISEASES

Satisfactory histopathological evidence of myocarditis and pericarditis due to virus disease exists. Finland[7] described such evidence in Influenza A infections and Gefter[6] described a myocarditis in six of seven patients dying of anterior poliomyelitis There is the monumental paper by Swann *et al.*[8] describing how German measles in the first trimester of pregnancy affects the heart of the fetus-in-utero. Mumps, influenza, infectious hepatitis, and yellow fever have all been recorded as producing associated myocardial changes.

It must be true if severe myocardial damage occasionally occurs with the above infections, that mild, unnoticed involvement probably occurs quite

frequently. However, the symptoms of fatigue and palpitation existing without other clinical evidence are not sufficient to justify a prolonged convalescence. With our present scanty knowledge it is possible that we might precipitate a severe cardiac neurosis if we gave too much attention to these common complaints.



FIGURE 2 Leishmanial form of *Trypanosoma cruzi* between the myocardial fibers

Infectious mononucleosis, a disease of unknown etiology, with protean manifestations, is known to affect the myocardium and pericardium. There are many reports of electrocardiographic abnormalities associated with this condition.[7,10] Allen and Kellner[9] described the heart of a young aviator, accidentally killed while flying three weeks after discharge from the hospital, having previously been admitted with infectious mononucleosis There was considerable round cell infiltration throughout the myocardium.

CASE 1: P. B., a previously well and healthy young man, aged twenty, was seen at 1·00 A M. on February 16, 1953 because of anterior chest pain The pain was substernal and unrelated to breathing The patient was restless in the bed trying to seek a comfortable position There was no radiation He was given a sedative and the same day an electrocardiogram (Fig. 3) showed R-S-T segment alterations compatible with acute pericarditis.

The next day, February 17, 1953, he complained of a sore throat. The pain in the chest was subsiding. He had a temperature of 38.3° C (101° F). The tonsils were enlarged and red. The cervical lymph nodes were enlarged and tender. The W.B.C. was 4,000 with thirty-eight per cent polys and sixty-two per cent lymphocytes, many of which were immature and degenerated and of the type seen in infectious mononucleosis. Penicillin was administered intramuscularly for several days.

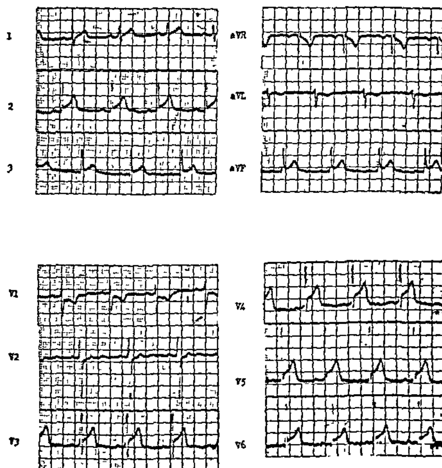


FIGURE 3. R-S-T segment alterations consistent with acute pericarditis in case of infectious mononucleosis

He made a slow but steady improvement. The temperature returned to normal in a week, and by that time the tonsils and cervical nodes were nearly normal. On February 26, the W.B.C. was 11,500 with seventeen per cent polys and eighty-three per cent lymphocytes. The latter cells again suggested the presence of infectious mononucleosis.

On March 10, the heterophile agglutination was 2 plus in a 1:256 dilution, and the EKG (see Fig. 4) was still abnormal. On March 23, the EKG (see Fig. 5) was still abnormal. The heterophile agglutination was reported as one plus in a 1:64 dilution. The blood smear still showed cells characteristic of

mononucleosis On April 20 (two months from onset) the heterophile agglutination was reduced to normal levels (one plus in 1:16 dilution) and the EKG (see Fig. 6) was normal. It was our final opinion that this young man had a myopericarditis associated with infectious mononucleosis and that the prolonged convalescence (two months) was justified (see Fig. 7).

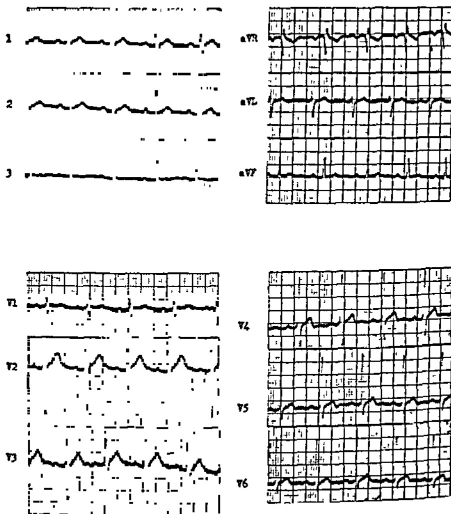


FIGURE 4 ECG in case of infectious mononucleosis with pericarditis on sixth day of disease

RICKETTSIAL DISEASES

Gore and Laphir[14] found evidence of myocarditis in twenty-three of forty-eight fatal cases of epidemic typhus and in nine of nineteen cases of RMSF. The same investigators also found pathologic evidence of myocarditis in all of 227 cases of scrub typhus.

BACTERIAL DISEASES

The common bacterial infections involving the heart are rheumatic fever, syphilis, and acute or subacute bacterial endocarditis. Rarely, how-

ever, a myocarditis is associated with a hemolytic streptococcal infection other than rheumatic fever. A small percentage of patients with *scarlet fever* develop a myocarditis and/or endocarditis, usually mild, and indistinguishable from that of rheumatic fever. The diagnosis of scarlet fever myocarditis usually depends on the development of cardiac enlargement, murmurs, and electrocardiographic changes Scarlatinal carditis

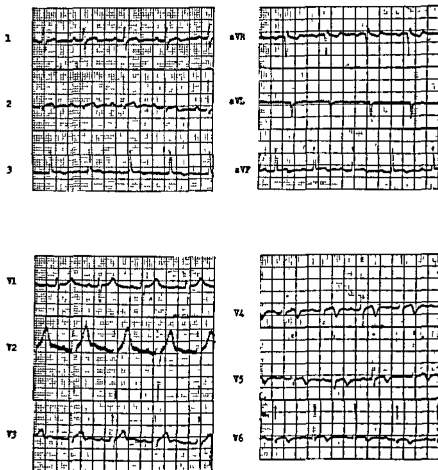


FIGURE 5 ECG in case of infectious mononucleosis with pericarditis on the twentieth day of disease

usually occurs earlier than rheumatic carditis. The active treatment of scarlet fever from the outset with adequate amounts of penicillin should prevent such complications. *Acute nephritis* in association with *acute hemolytic streptococcal* infection is also often associated with an acute myocarditis, cardiac enlargement, and heart failure. The microscopic picture is again similar to that of acute myocarditis in general, *i. e.*, myocardial necrosis with infiltration by inflammatory cells followed by fibroblastic proliferation. *Undulant fever*—brucella organisms may also rarely involve

the heart, producing an endo-, peri-, or myocarditis. *Pneumonia*, when severe, may be associated with certain arrhythmias and with T wave changes in the EKG. There may be some actual myocardosis as a toxic effect from the infection, but this is usually not severe. Again the postpneumonic symptoms of fatigue and palpitation are more liable to be the result of the

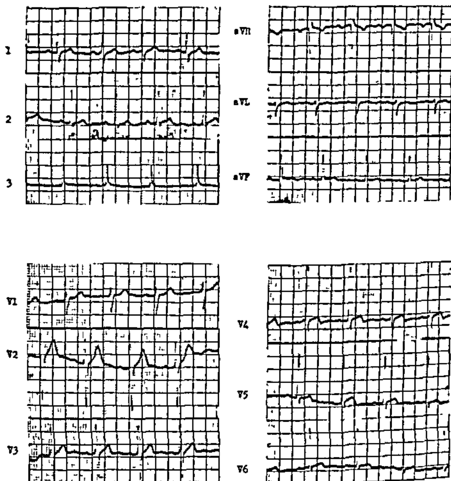


FIGURE 6. ECG in case of infectious mononucleosis with pericarditis on the thirty-fifth day of disease The tracing is returning to normal

systemic effects of the infection. The well known complications of pneumococcic bacterial endocarditis and pericarditis are discussed elsewhere

Typhoid Fever, like pneumonia, may prove an overwhelming strain on one who already has a serious cardiac disability but in itself it rarely causes heart disease of any severe or permanent degree. There is an occasional instance of endocarditis, pericarditis, myocarditis, or endarteritis The postinfectious asthenia with low blood pressure, rapid pulse, and weakness does not respond to digitalis.

Tuberculosis affects the heart in many ways. It is a common cause of acute and chronic pericarditis. This may result from the breakdown of

contiguous nodes and need not be from miliary spread. Pericardial effusion commonly occurs. It is usually hemorrhagic. It often develops slowly, without symptoms, in contrast to the dyspnea and pain of the rapid developing rheumatic effusion.

CASE REPORT: A. B., a sixty-five year old Italian mill worker presented himself complaining "they won't letta me work, Doc. They saya my heart is too

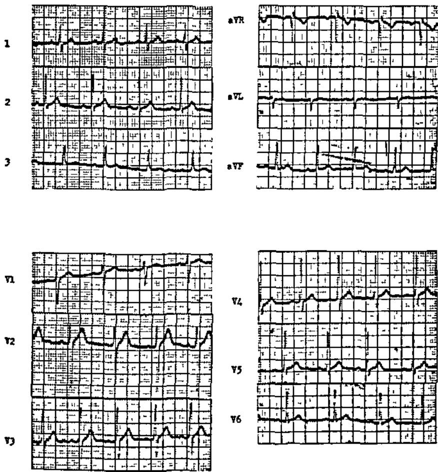


FIGURE 7 ECG two months following an acute pericarditis due to infectious mononucleosis The tracing is now normal

beeg. Me feela good" Examination found a rugged muscular man, 1 52 meters (5 feet) tall, weighing 75 kg (165 pounds) Blood pressure 110 90. Normal rhythm 100 per minute The cardiac enlargement, evident by x-rays of the chest, was not apparent clinically He had a barrel chest which seemed resonant throughout. there were no murmurs or friction rubs. The cardiac silhouette was rather characteristic of a pericardial effusion (see Fig 8) and his electrocardiogram showed low amplitude of all the complexes (Fig 9)

His story revealed that x-rays *of his heart* two years before showed enlargement. He was admitted to the *hospital and* a pericardial tap was performed on four occasions, usually with the *removal* of 500 to 900 cc. of turbid *amber fluid* Air was injected into the *pericardial* sac after the removal of *the fluid*. X-rays at this time showed *a thickened* pericardium (*Fig. 10*). *Cultures* of the fluid for *tubercle bacilli* have been *sterile but it* is considered the most likely cause of his pericardial effusion for it existed *so long in* the absence of symptoms.



FIGURE 8 Cardiac silhouette *of patient* with pericardial effusion, considered due to tuberculosis The patient was *asymptomatic*

Tuberculosis is *also* a common cause of constrictive pericarditis which leads to pseudocirrhosis *of the* liver with ascites.

Miliary tuberculosis with *hematogenous* spread may involve the endocardium, myocardium, and pericardium. Solitary tuberculomas or cold abscesses may *occur* in the myocardium.

Of particular interest is the chronic cor pulmonale with right ventricular hypertrophy, *venous engorgement*, and hepatic enlargement resulting from the pulmonary *hypertension* which so often accompanies a severe, diffuse pulmonary *fibrosis*. This serious condition must be distinguished from the commoner *asthenia*, slender physique or pthisic habitus wherein the heart is vertical *in position* (part of the visceroptosis) and where premature contractions and *even* episodes of ectopic tachycardia are not uncommon [12]

The meningo*coccus*, gonococcus, and staphylococcus may involve the heart usually *causing* bacterial endocarditis or pericarditis. However, even *in the absence* of endocarditis, the myocardium may be the site of pyogenic abscesses (Fig. 11); this section shows a pyogenic abscess of the myocardium due to *hemolytic* staphylococcus alba. The patient had a severe

overwhelming septicemia due to this organism with multiple abscesses in the heart, spleen, kidneys, and brain.

FUNGUS DISEASES

Actinomyces has long been known to invade the heart, pericardium, and contiguous structures as it progresses from an esophageal or periesophageal lesion.

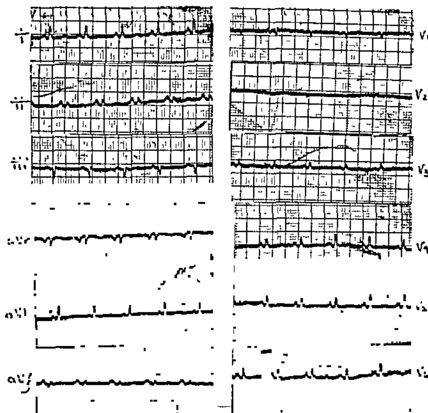


FIGURE 9 ECG of asymptomatic patient with large pericardial effusion considered due to tuberculosis Note the low voltage of all complexes

Other fungi· More recently we have been aware of fungous diseases involving the endocardial surfaces of the heart valves, following massive penicillin therapy for bacterial endocarditis.

CASE REPORT: C. D, a sixty-seven year old male had a persistent enterococcic (*Strep. faecalis*) septicemia in 1952 and 1953. Prior to this event he was known to have rheumatic type heart disease with cardiac enlargement and mitral insufficiency. His blood pressure was usually 190 110. He never showed any evidence of congestive failure. At the time of his septicemia (which followed a course of prostatic massage for chronic prostatitis) it was assumed that he had a subacute bacterial endocarditis Initial treatment with 2.4 million units of penicillin daily for one month was followed by remission of symptoms and fever and by a negative blood culture However, after being symptom free for two months, he relapsed and treatment was reinstituted, using six million

units of penicillin daily together with 1 Gm. of streptomycin. All drugs were given intramuscularly for six weeks. Complete recovery ensued and the patient returned to work as an accountant without a sick day for the next two years

On June 4, 1955 he awoke atoxic and confused. The first thought on seeing him was that of cerebral vascular accident. However, his temperature was 39.7° C. (103.4° F.). A blood culture revealed hemolytic *Staph. albus*. Therapy

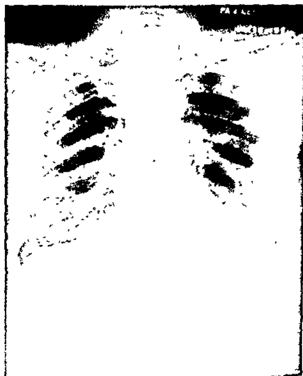


FIGURE 10 Cardiac silhouette of patient with pericardial effusion after effusion had been tapped and air introduced into pericardial cavity

was started and included 100 million units of penicillin and 2 Gm. of ilotycin intravenously, as well as 1 Gm of streptomycin intramuscularly daily. He died on the fourth hospital day having no clinical improvement from the therapy. His autopsy showed multiple abscesses of the heart (see Fig 11) and the mycelia of a fungus in the endocardium of the mitral valve (see Fig 12 and Fig 13).

MYOCARDITIS

Feidlers myocarditis[13] is a nonspecific myocarditis histologically no different than any acute myocarditis. Again there is the usual necrosis with infiltration by inflammatory cells and early fibroblastic proliferation. It is not especially interstitial or patchy. Acute myocarditis, of unknown etiology, often is designated Feidlers myocarditis but as understanding grows it is assumed that this grab bag containing myocarditis of all sorts will diminish.

Acute or subacute myocarditis of any cause is often associated with marked cardiac enlargement, pallor, cyanosis, prostration, dyspnea, tachycardia, low blood pressure, and low pulse pressure, increased venous pres-

sure, engorged neck veins, and congestion of the liver; there may be tricuspid insufficiency and pulsating peripheral veins. There is usually a mitral systolic murmur and often a gallop rhythm. The patient is usually quite sick with a seriously reduced cardiac reserve The differential diagnosis includes myocarditis of rheumatic etiology, beriberi, heart disease,



FIGURE 11 Abscess of myocardium due to hemolytic staph alba This abscess was a part of a generalized septicemia

or the possibility of an intracardiac shunt The bulging of the precordium with each heartbeat makes you think the heart is working against an obstruction, but this vigorous pulsation is usually due to right ventricular enlargement. Adhesive pericardialmediastinitis must also be considered.

We had such a patient on whom an angiogram was done. The pictures strongly suggested a filling defect in the right auricle. We now know that such an appearance can also be produced by tricuspid insufficiency. At the time we thought of such things as a bal-valve thrombus in the right auricle or of a primary tumor of the heart. It was decided wise to explore the patient's right auricle using the artificial heart-lung machine of Dr. John Gibbon to by-pass the circulation from the right side of the heart. Nothing was found at operation except the tricuspid insufficiency, but at the autopsy

twelve hours later, he was found to have an acute myocarditis and Ebstein's disease.

TRICHINIASIS

Heartworm is a by-word with the laity who frequently think of it in reference to heartworms in dogs. While worms are sometimes found in the chambers of the dog heart, such is not the case in the human heart. Such objects as have been suspected as being worms in the human heart were

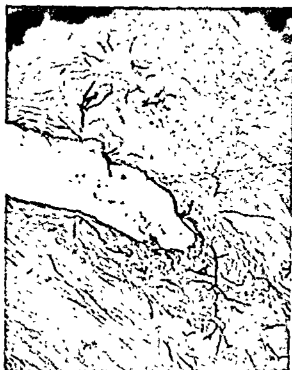


FIGURE 12. Mycelia of a fungus in the heart valve of a patient who died of a generalized septicemia following large doses of penicillin

probably small emboli from peripheral vessels. However, it is well known that the Trichina worm, so called, does invade the human myocardium as it does the skeletal muscles. This is especially true in the heavily infested cases but may be true in all cases to a lesser extent. Distinct electrocardiographic changes are often present such as alteration in the T waves and alteration in the Q-R-S complexes during the stage of migration of the larvae from the wall of the intestinal tract to the skeletal musculature via the lymphatics. Death rarely may ensue from the myocarditis so produced. A typical case is reported from the files of the Pennsylvania Hospital:

CASE 1· C. S., a twenty-six year old single, colored female was admitted February 10, 1935, complaining of dizzi ... and swelling of the eyelids. She stated that she first n ... morning of February 7. Systemic review ... digestive complaints following the ingestion of pork.

Examination revealed an acutely ill but well-developed young Negress Her temperature was 39 9° C. (103 8° F). The pulse rate was 136 per minute and

the blood pressure 105/70 Bilateral edema of the eyelids and periorbital tissues was present. Moderate submaxillary adenopathy existed. The heart sounds were distant.

Laboratory studies revealed a normal urine analysis except for a trace of protein. The blood Wassermann and Kahn reactions were positive. During her course in the hospital she had a persistent leukocytosis which ranged from



FIGURE 13. Mycelia of a fungus in the heart valve of a patient who died of a generalized septicemia following large doses of penicillin.

13,100 to 22,000 and an eosinophilia from six to sixteen per cent. Spinal fluid sediment was negative for Trichinae

The electrocardiograms taken on February 11 and 12 showed auricular tachycardia with slurred Q-R-S complexes of low amplitude in all leads An electrocardiogram on February 16 revealed sinus tachycardia, left axis deviation, and slurred Q-R-S complexes in limb Lead III (see Fig 14).

Deltoid muscle biopsy showed *Trichinae spiralis* infestation.

In spite of general supportive therapy, the patient became weaker and stuporous. She died on February 16, 1935

At necropsy the heart weighed 190 Gm It showed many pin-point gray-white spots present throughout both ventricles which microscopically showed extensive areas of focal necrosis with fragmentation and dissolution of the muscle fibers No Trichinae were found, but encysted Trichinae were observed in the muscles throughout the body with focal areas of necrosis and inflammation

The pathologic diagnosis was acute trichiniasis with Trichinae spiralis infestation of the skeletal muscles and heart.

NEOPLASMS OF THE HEART

Neoplasms of the heart occur uncommonly and are rarely of clinical importance because they so often affect the individual who is suffering

from malignant disease elsewhere. Secondary malignancies or metastases to the heart and pericardial structures are most often the result of malignant melanoma or are found primarily in the uterus, rectum, kidney, bronchus, breasts, testicle, gallbladder, or other distant structures. Forty-eight per cent of the metastatic lesions, however, are primary in the bronchus and breasts. Primary malignancy or tumor of the heart is considerably less frequent than metastatic tumors. When it occurs, it is most commonly a

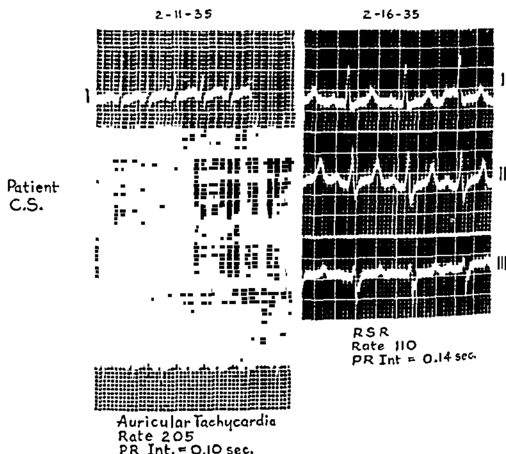


FIGURE 14 Electrocardiographic changes in trichiniasis

sarcoma of undefined character. Other primary tumors are described as myxoma, rhabdomyomas, carcinoma, fibromas, lipomas, angiomas, teratomas, xanthomas, and cystomas.

A clue to antemortem recognition might be an unexplained and unusual size or shape of the heart on x-ray examination or varieties of auricular or intraventricular heart block in the electrocardiogram. Antemortem diagnosis is of little practical importance since there is no treatment known to be effective except the x-ray treatment of malignant lymphomas (*i. e.*, Hodgkin's disease).

Primary sarcomas and lipomas and more recently cavernous angiomas and malignant angioendotheliomas of the pericardium have been described but, like the heart, the pericardium is most often affected by metastatic

spread from primary sources elsewhere. The syndrome of constrictive pericarditis has been described as due to neoplastic involvement of the pericardium

Perhaps 100 cases of undifferentiated sarcoma primary in the heart have been described. To this list is added the following additional case from the records of the Pennsylvania Hospital:

CASE 1: W. H. S, a sixty-six year old colored male, was admitted to the hospital January 24, 1944, complaining of constant right anterior chest pain of six weeks' duration aggravated by coughing Blood-streaked sputum was present for one week before admission

Examination revealed a thin, well-developed colored male in no acute distress. Temperature was 36 6° C (98° F) Pulse rate was 84 per minute Respirations were 20 per minute. The blood pressure was 110 68 A hard, tender nodule 2 cm. in diameter was palpable in the right supraclavicular area with bilateral axillary lymphadenopathy Increased breath sounds were audible over the upper lobe of the right lung Marked clubbing of the fingers and toes was present, and the liver was palpable 10 cm. below the right costal margin.

A leukocytosis and a secondary anemia were present throughout his hospital period. A chest x-ray film revealed an area of infiltration in the right upper lobe with cavity formation

The patient's course was steadily downhill with the development of a fungating necrotic mass in the left upper maxilla He died March 16, 1944

At necropsy a gray-white linear nodule was discovered along the annulus of the tricuspid valve beneath the endocardium Beneath one of the tricuspid cusps was a rounded gray mass 1 5 cm in diameter, projecting into the ventricular cavity. Similar nodules were found throughout the right ventricular myocardium. A gray-white nodule, ulcerating through the endocardium, was also found in the left ventricle near the septum Several discrete tumor masses were found in the left ventricular myocardium Microscopically, these tumor masses showed cells with considerable disorder in their arrangement and with no encapsulation. Some were elongated, some spindle-shaped and polygonal. The nuclei were bizarre in size and shape, and all were hyperchromatic. The heart muscle fibers were separated in these areas Similar findings were observed in the metastases to the lungs, adrenals, left maxilla, and tracheobronchial lymph nodes. In these areas characteristic spindle-shaped cells with lacing of the cells were noted. A suggestion of cross-striation, as seen in the myocardial fibers, was noted in the metastases. The pathologic diagnosis was an indifferentiated sarcoma probably primary in the heart. Additional autopsy findings were a squamous carcinoma of the lung and a benign cystadenoma of the right kidney

REFERENCES

1 Kay, C F, and Livingood, C S Myocardial Complications of Cutaneous Diphtheria. Bull U S Army Medical Dept 4 462 1945

2 Sutherland, J, and Willis, R A Endocarditis Due to Diphtheroid Bacillus Structurally and Culturally Resembling Diphtheria Bacillus J Path. & Bact 43 127, 1936

3 Jones, T D, and White, P. D The Heart After Severe Diphtheria American Heart, 3 190, 1927

4 Stroud, W. D The Importance of Follow-Up Work in Connection with Diphtheria

5 Finland, M, Parker, F, Jr, Barnes, M W, and Joliffe, L S Acute Myocarditis in Influenza A infections. Two cases of nonbacterial myocarditis, with isolation of Virus from the Lungs Am J M Sc 209 455 1945

6 Gelter, W I, et al: The Heart in Acute Anterior Poliomyelitis. American Heart J. 33.228, 1947.
7 Evans, W F., and Graybill, A.: Electrocardiographic Evidence of Cardiac Complications in Infectious Mononucleosis American J. M. Sc. 211:220, 1946
8 Swann, C., Tostevin, A. L., Moore, B, Mayo, H., and Bartram Black, G H: Congenital Defects in Infants following Infectious Diseases During Pregnancy, etc M J. Australia, 2:201, 1943.
9. Allen, F H., Jr, and Kellner, A.: Infectious Mononucleosis, and Autopsy Report American J Path 23:463, 1947.
10 Jaffe, H. L, Field, L. E, and Master, A. M: The Electrocardiogram in Infectious Mononucleosis, New York J. Med 48.1382, 1948.
11 Cruz, O, and Chagas, C.· First Description of American Trypanosomiasis in Brazil, 1909 Foreign Letters, J A.M A. 121:65, 1943
12 Stroud, W D: personal communication
13 Feidler, A.· Ueber Akute Interstitielle Myokarditis Festschrift d Stadtkrankindhauses Dresden-Freedrickstadt, 1899
14 Gore, I, and Laphir, O Am Heart J. 34:831, 1947.

44

Periarteritis Nodosa

For the best understanding of periarteritis nodosa, its signs, symptoms, and other clinical considerations, one should see a text dealing with all phases of internal medicine, including neurology.

Since the last edition of this book, periarteritis nodosa has been regrouped in its editorial handling. It is now commonly found among the collagen diseases rather than among the diseases of the heart and circulation. This regrouping has not simplified the definition of the disease nor has there been new light on incidence and etiology In the realm of pathology there has been consolidation of ideas so that there is no longer much divergence as to recognizing the lesions histologically. The purely cardiovascular implications have been well described by Griffith[1] in 1951 by study of sixteen cases from one hospital. Experience at the Cincinnati General Hospital is much the same. One would expect no regional peculiarity in the manifestation of the disease, but review of case reports from numerous sources is subject to the vagaries of selection for reports. Several publications from Cincinnati are consolidated here with regard to cardiovascular disease.[2,3,4]

Table 1 shows this experience at autopsy in the years 1933 to 1952 inclusive, there being forty-five cases in 14,275 autopsies.

TABLE 1

	Periarteritis nodosa	*Secondary periarteritis nodosa*	*Hypersensitivity angiitis*
Number of cases.	14	21	10
With hypertension .	10/12	21	3
Clinical congestive failure	5	4	1
Pathology of congestive failure	5	7	0
Uremia	0	17	4
Coronary involvement	13	4	4
Myocardial infarct, clinical	2	0	0
Myocardial infarct, pathological	3	0	0
Peripheral vascular disease	0	0	0
Duration of disease	5-52 weeks	xxx	6-32 days

For this scheme of classification we are indebted to Dr. Pearl Zeek, formerly a pathologist at the Cincinnati General Hospital.[2] For this chapter it is sufficient to state that typical arterial lesions were found in all, but her search of the arteries of all patients dying as a result of hypertension revealed a large number of so-called secondary necrotizing angiitis.

The clinical manifestations of primary periarteritis nodosa were much the same as published for a number of years and from a number of sources. This is typified by a long clinical course with gastroenteric symptoms, peripheral neuropathy, hypertension, and occasionally with eosinophilia, but frequently with fever and leukocytosis. In contrast, the clinical fea-



FIGURE 1 Fibrosis … necrosis resulting from thrombosis of c… General Hospital No N-47-1… —Malignant hypertension, congestive failure due to arteritis or lupus Biopsy was not diagnostic.

tures of hypersensitivity angiitis were more conspicuous fever, skin rash, nephritis, myocarditis, and a relatively short and usually fatal course. Secondary periarteritis nodosa is that which is concurrent with hypertension. Because of the importance of biopsy in diagnosis, the histopathology is set forth in detail (Figs. 1 to 5).

The diagnosis of this disease depends largely on a high index of suspicion and primarily upon taking a biopsy. In any situation of unexplained fever with hypertension and pain, whether it be abdominal or in the extremities, *the disease should be suspected. Lesions of the peripheral or central nervous system frequently give the most convincing suggestion*



FIGURE 2 Acute coronary periarteritis nodosa The lesion is characterized by fibrinoid necrosis of media best illustrated on the extreme right The lumen is partly occluded by a thrombus The adventitia is edematous and the site of a rather sparse pleomorphic leukocytic exudate This lesion involving the larger subepicardial coronary artery segments may cause sacular aneurysm formation, most frequently involving only a portion of the artery's circumference × 160 Cincinnati General Hospital No N-36-655, Male, age twenty-eight Clinical diagnosis—Periarteritis nodosa, terminal pneumonia

that the disease present. Biopsies of skeletal muscle have been most used. It is recommended that a generous portion of muscle (gastrocnemius and pectoral) be taken for this examination and that repeated sections be made to search the arteries. When the disease is present in the form of hypersensitivity, angiitis biopsy is not feasible In the eleven cases described from the Cincinnati General Hospital, the diagnosis was not made in a single instance. But now, in any condition which appears as a *hypersensitivity reaction of skin, bone marrow, and with diffuse pulmonary* lesions, the disease should be suspected and treatment started forthwith.

Treatment: The treatment has been symptomatic and still is mainly. When cortisone first became available it was used in this situation, as would be expected from the nature of the lesions and from the belief that it was indeed a display of hypersensitivity or an antigen antibody reaction. The results of this form of treatment with its many modifications is still



FIGURE 3. Biopsy of gastrocnemius muscle from a case of generalized periarteritis nodosa The small artery's media is necrotic and fibrinoid The surrounding exudate is largely monocytoid with some granulocytes and lymphocytes × 650 Cincinnati General Hospital No N-36-655 Muscle biopsy of case in Fig 2.

a matter of doubt. There is not in current literature any consecutive series under observation for a long enough time to tell the value of this treatment. In characteristic periarteritis nodosa, healing does occur spontaneously and perhaps is accelerated by the use of the steroid. In typical periarteritis nodosa, the process of healing causes infarction of numerous organs, especially kidney and the gastroenteric tract, and the symptoms

are worsened by the very act of healing In autopsy material, treated or untreated, active inflammation may be found simultaneously with very definite healing. The treatment of hypersensitivity angiitis, as has been recorded, is apparently more successful. The usual advice about steroid therapy is that it should be given in short courses in the acute phases and



FIGURE 4 Acute hypersensitivity coronary angiitis The vessel is small and within the myocardium, thus accorded a degree of protection from the stresses of intravascular systolic blood pressure The media is almost completely replaced by fibrinoid [illegible]
however, in [illegible]
Cincinnati G[illegible]
diagnosis—F[illegible]

discontinued as soon as possible. A recent search of the records at the Cincinnati General Hospital finds ten patients that have been diagnosed as periarteritis nodosa, three of these treated with cortisone. In none was there a fortuitous and happy result. In one, the patient developed severe hypertension and convulsions and the remedy had to be stopped. Another

patient, treated with aspirin over a long period of time, had a spontaneous remission and was able to go to work. The disease relapsed within a year and he was then treated energetically with cortisone without any notable improvement. Autopsy showed lesions in all stages of healing and in all stages of advancing.

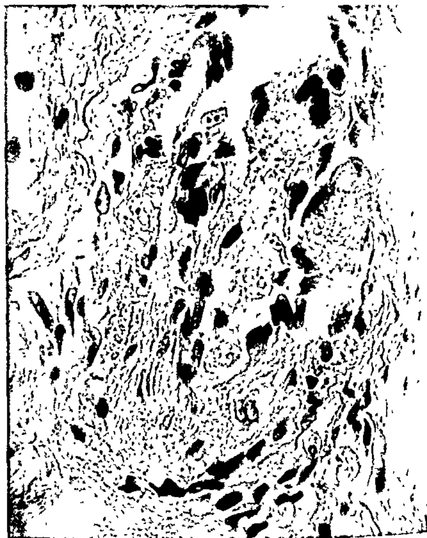


FIGURE 5 Angiitis of a small coronary artery with fibrinoid necrosis of entire ... n upper left corner. The lumen is partly ... e leukocytic exudate The lesion, identical to ... from the heart of a patient with secondary ... × 650. Cincinnati General Hospital No N-39-60 Male, age thirty-eight. Clinical diagnosis—Malignant hypertension Uremia

In this series typical lesions were found in a patient who was correctly diagnosed as disseminated lupus, thoroughly treated with cortisone, died of miliary tuberculosis, and showing acute periarteritis nodosa. This concurrence of periarteritis with lupus and rheumatoid arthritis has been

frequently reported as well as the clinical emergence of necrotizing angiitis during steroid therapy.

REFERENCES

1. Griffith, G C. & Vural, I L : Circulation 3 481 (April) 1951
2 Zeek, R M · Periarteritis Nodosa A Critical Review, Am Jour Clin Path 22 777, 1952.
3 Blankenhorn, M A , Zeek, P , and Knowles, H C , Jr · Periarteritis Nodosa and Other Forms of Necrotizing Angiitis A Clinical and Pathological Correlation, Transactions of the Assoc of American Physicians, 66 156, 1953
4 Blankenhorn, M A , Knowles, H C , Jr Periarteritis Nodosa Recognition and Clinical Symptoms, Annals of Internal Medicine, Vol 41 (Nov) 1954

ORVILLE HORWITZ, M.D.

45

Thromboangiitis Obliterans
(Buerger's Disease)

Definition: Thromboangiitis obliterans is an inflammatory obliterative condition of the medium-sized and small veins and arteries occurring almost exclusively in white men under the age of fifty Segments of the vessels are involved causing ischemia and often gangrene.

Historical: Von Winiwarter[1] first described a condition in a fifty-seven year old man who had been having symptoms for over ten years. From his description the disease was almost certainly what is now known as thromboangiitis obliterans. In Buerger's original paper[2] in 1908 a new concept of the pathogenesis was developed. He later[3] described purulent foci and giant cells which formed an occluding mass in the vessels. He described three stages of the disease: First, the acute inflammation of the vessels which leads to thrombus formation; second, the organization and canalization of the thrombi; and third, the transformation of a patent vessel into a solid fibrinous cord. Because of this original and fairly complete description the condition is also known as "Buerger's Disease." Other names include obliterative arteritis of the young, juvenile gangrene, presenile gangrene, presenile arteriosclerosis, Russian, Jewish, or Yiddish disease, and nonsyphilitic endarteritis. Although Erb, as early as 1904, considered tobacco to be a significant contributing cause of the condition, a history of the disease would not be complete without mentioning Silbert's[4] contribution of 1927 which stated that whatever the underlying cause might be, prolonged smoking was certainly the immediate causative factor.

Pathology: Thromboangiitis obliterans is primarily a disease of the medium-sized and small blood vessels, arteries being involved more frequently than veins of similar dimensions. Larger vessels such as the external iliac become involved only when the disease is fairly violent and of long duration. The lesion is inflammatory but not suppurative. A thrombus is formed and becomes organized by means of a heavy growth of fibroblasts. During this organization some recanalization of the thrombus may occur. Organic segmental occlusion of the vessel is usually permanent and complete. Various occlusions of a single vessel are not unusual.

Occluded segments accompanied by contraction in the region of the occlusion lead to ischemia and possible gangrene of the part supplied by the vessel. A nerve accompanying such a vessel may be bound to it by perivascular fibrosis.

As contrasted to the histopathology of arteriosclerosis there is little or no atrophy in the muscular layer, no hemorrhage into the vascular wall,

no cholesterol, fat deposits, or calcification, and little or no proliferation or splitting of elastic lamina.

The most striking changes of a pathologic-physiologic nature are due to the decreased blood flow to the peripheral extremities. The rate of flow to the skin of the digits and to the muscle is greatly decreased. The capac-

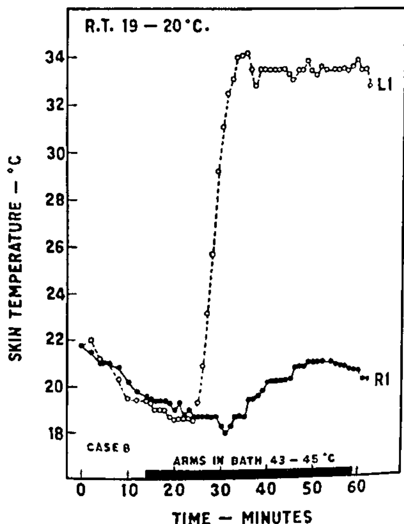


FIGURE 1· *A* Vasodilatation response in a patient with thromboangiitis obliterans involving the right foot. The skin temperature rose normally on the left foot but only slightly on the right

ity for blood flow to a toe may be reduced from 60 to 70 cc./100 cc of tissue/minute to 1 cc./100 cc. of tissue/minute[5,6] (Fig. 1). The amount of blood which reaches a muscle such as the gastrocnemius is markedly decreased, resulting in intermittent claudication, an indication that the blood flow is insufficient to meet the increased requirements of exercising muscle The ischemia produced in exercising muscle under such circumstances is manifested by intense pain promptly relieved by rest, or if larger muscle groups are involved, by weakness as well as pain.[7] Intermittent claudica-

tion is almost invariably the result of arterial occlusion but occasionally is *caused by abnormal vasoconstriction.*

Etiology: The exact etiology of thromboangiitis obliterans is unknown. Silbert[8] has stated that it is caused by smoking and documented his statement by showing progression of the disease in those who continued to

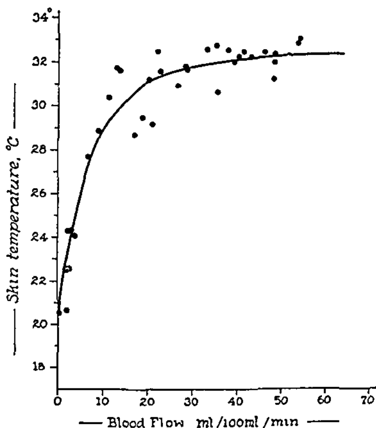


FIGURE 1. *B* The relationship in toe-tip between skin surface temperature and blood flow measured plethysmographically at approximately the same room temperature (20°C) indicated in Fig 1A. By interpolating it can be seen that the blood flow of the foot affected by thromboangiitis is approximately 1 to 2 cc per 100 cc. of tissue per minute; whereas in the control foot the blood flow is 60 to 70 cc. per 100 cc of tissue per minute

smoke and the arrest or regression in those who actually stopped smoking. Eisen *et al.*[9] suggest that smoking causes changes in the adhesive quality of platelets which can be detected by an appropriate technic in patients suffering from thromboangiitis obliterans. A rare patient has been known to have thromboangiitis obliterans who did not use tobacco in any form.[10]

Symptoms and Signs: The involvement of the extremities is generally asymmetrical. The onset of the condition occurs almost invariably in white males below forty years of age and may be acute or insidious. In about one-half the cases it is preceded or accompanied by segmental transient migratory phlebitis of the smaller superficial veins. Intermittent claudication is

TABLE I

	Thromboangiitis Obliterans (Buerger's Disease)	*Arteriosclerosis*	*Arterial Embolism*	*Raynaud's Disease*
Sex distribution	98% male	Male more frequent	About equal	90% female
Age distribution (onset)	Under 40	Usually over 50 (Except in diabetes)	Any age	25–50
Etiology	Probably tobacco	Unknown. High fat diet?	Almost always auricular fibrillation, myocardial infarction or mitral stenosis	Sometimes psychosomatic
Extremity involvement	Generally asymmetrical	Generally asymmetrical unless aorta is involved	Asymmetrical unless aorta is involved	Symmetrical
Onset	May be acute and preceded by migratory phlebitis	Usually insidious	Sudden, usually with severe pain	Often in cold weather and preceded by psychic trauma
History of phlebitis	Common (migratory)	Only coincidental	Only coincidental	Only coincidental
Intermittent claudication	Common	Common	May be present later	Absent
Absent pulses	Common in upper and lower extremities	Rare in upper and common in lower extremities	In artery involved	Occurs only in late and extreme cases
Edema	Common	Only if infection is present	Rare	Rare
Skin (if involved)	Thin, atrophic and reddened	Thin, often hairless	Normal	Normal
Nails (if involved)	May stop growing	Thickened	Normal	Normal
Rubor of skin on dependency	Common	Common	May be late sign	Rare
Ulcers (if any)	Moist, deep, inflamed and invasive	Dry and superficial	May be present later	Dry and superficial
Optic fundi	Normal	Often silver wiring	Usually normal	Normal
X-rays of extremities	Normal	Often calcification of periph. arteries	Usually normal	Normal
Capacity for blood flow as measured by vasodilatation test	Decreased in involved extremity	Decreased in involved extremity	Decreased in involved extremity	Normal unless in spasm



Acute migratory phlebitis of thromboangiitis obliterans. A dorsal vein of the foot is thrombosed, hard, and tender. The characteristic discoloration of the overlying skin is at first pink, and some days later brown.

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common. Absent pulses occur in the upper and lower extremities. Ischemic ulcers may develop and are *generally moist, deep, inflamed, and invasive.* These ulcers are frequently accompanied by local edema. The skin is thin, reddened, and atrophic. The nails may stop growing. Rubor of the skin on dependency is not an infrequent finding. X-rays of the extremities will show no calcification of the peripheral arteries but may give evidence of osteoporosis or osteomyelitis in more advanced cases. Capacity for blood flow as measured by a vasodilatation test is decreased in the involved extremities. Examination of the optic fundi is likely to be normal.

Differential Diagnosis: The differential diagnosis is, for the most part, from other conditions which cause arterial occlusion and gangrene of the extremities (Table I).[11] The most important ones are arteriosclerosis, embolus, and Raynaud's disease. Other conditions which may be confused with thromboangiitis obliterans are periarteritis nodosa, which rarely produces absence of pulsations; ergotism, a rare condition, and venous occlusion of large veins, a condition in which cross-sectional edema is accompanied by generalized venous distention.

Prognosis: The prognosis of this disease may vary from excellent to multiple amputations causing loss of legs and fingers This apparently depends upon whether or not the patient is able to stop smoking. In the lower extremity mid-thigh amputation is not uncommon. However, in the upper extremity amputation proximal to the digits is rare.

Treatment: By far the most important thing in the treatment of thromboangiitis obliterans is the abstinence from tobacco, which not only is a strong vasoconstrictor capable of overcoming the effect of any vasodilator presently known, but is also, in all probability, directly or indirectly the etiological agent.[8] The idea of treating a tobacco-using patient with this condition is paramount to treating, by oral medication, a man whose feet are in a meat grinder.[12] Sympathectomizing, when smoking has not been stopped, may well give the patient a sense of false security.

The rest of the treatment is very much the same as the treatment of any other peripheral arterial obliterative disease and may be divided into two parts: The first is designed to allow as much blood as possible to reach the ischemic part by inducing maximum vasodilatation. The second is designed to decrease the local demand for blood by the prevention and treatment of traumatic and infectious processes.

Measurements used to induce maximum blood flow are as follows:

1. *Vasodilator Drugs.* Alcohol is probably still the ideal vasodilator and except for its habit forming tendencies could be used in most cases unless otherwise contraindicated.[13] It has the advantage of increasing digital cutaneous blood flow as well as muscular blood flow in the legs without causing changes in blood pressure or cardiac output. Priscoline[14] and ilidar (25 to 50 mg. three times daily) are useful for increasing the flow to the skin of the digits. Niacin (50 mg. four times daily) is probably as effective as any drug in increasing muscle flow but causes an actual decrease in digital cutaneous flow.

confined to bed a thermoregulated cradle kept at approximately 33°C. is also useful[15] The best rule for the application of heat to an extremity in which there is no neuropathy is to keep the extremity as warm as possible without causing discomfort.

3. *Position.* Clinically and by measurements of oxygen tension[16] the most efficacious position for patients with ischemic feet was found to be produced by placing 15 cm. (6 inches) blocks under the legs at the head of the bed, thereby causing slight dependency of the feet.

4. *Buerger's Exercises and Oscillating Bed.* These procedures are useful in alternately filling and emptying the capillaries of the legs by gravity. The time during which the legs are in the "down position" should exceed the time in which the legs are in the "up position" by approximately three to one.

5. *Bed Rest.* Bed rest is mandatory in patients who have ischemic pain produced by little or no exertion, or ischemic ulcers.

6. *Sympathectomy.* Sympathectomy may be useful in patients with high vascular tone who give evidence of benefit from a paravertebral nerve block. This procedure seldom benefits intermittent claudication.

7. *Arterial Graft.* Since the arterial lesion of Buerger's disease is nearly always peripheral to the knee, arterial grafts are not often practical. The subject of arterial graft is discussed elsewhere in these volumes.

Methods for decreasing the demand for blood:

1. *Avoiding Trauma to the Extremity.* This includes wearing wide toed shoes and thick, warm, loose socks, soaking the feet in warm water before cutting the nails and other common sense precautions. Lanolin should be applied to overly dry feet and powder to overly moist feet. With bed-ridden patients special precautions should be taken to avoid pressure to the heels, toes, and malleoli from sheets and mattresses.

2. *Control of Infections.* Any infection should be treated vigorously by an appropriate antibiotic and saline soaks. Desenex® ointment and powder is useful in the treatment of dermatophytosis or "athlete's foot." Local bacterial infections often respond to the application of chloresium ointment which seldom causes local allergic reactions.

The migratory phlebitis of Buerger's disease does not respond to anticoagulant therapy.

REFERENCES

1 von Winiwarter, F · Ueber eine einenthumliche Form von Endarteritis und Endophlebitis mit Ganran des Fusses, Arch. f klin Chir 23·202, 1879
2 Buerger, L.: Thromboangiitis obliterans A study of the vascular lesions leading to presenile spontaneous gangrene, Am. J M. Sc 136 567, 1908
3 Buerger, L · The circulatory disturbances of the extremities, including gangrene and trophic disorders, W B Saunders Company, Philadelphia, 1924
4 Silbert, S : Studies on thromboangiitis obliterans (Buerger) II. The effectiveness of therapeutic procedures, J A.M A 89:964, 1927.
5 [illegible] of diagnostic
[illegible] oes
6. [illegible] ph.

7. Hitzrot, L H., Naide, M , and Landis, E M Intermittent claudication studied by a graphic method, Am Heart J 2 513, 1936
8 Silbert, S : Etiology of thromboangiitis obliterans, J A M A 129 5, 1945
9 Eisen, M. E , Tyson, M C , Michael, S , and Baumann, F Adhesiveness of blood platelets in arteriosclerosis obliterans, thromboangiitis obliterans, acute thrombophlebitis, chronic venous insufficiency, and arteriosclerotic heart disease, Circulation 3 271, 1951
10 Allen, E V , Barker, N W., and Hines, E A , Jr Peripheral Vascular Diseases, p 274, W. B Saunders Co , Philadelphia, 1955
11. Horwitz, O : Cardiovascular Brief Diagnostic points of the commonest peripheral arterial diseases, Penna Med J 57 663, 1954
12 Horwitz, O : Peripheral Arterial Disease Current Therapy, p 208, (February) 1954.
13 Horwitz, O Certain pharmacological properties of alcohol, nicotine and caffeine, J. Aviation Medicine 19 179, 1948
14 Horwitz, O , Montgomery, H , Longaker, E D , and Sayen, A Effects of vasodilator drugs and other procedures on digital cutaneous blood flow, cardiac output, blood pressure, pulse rate, body temperature, and matabolic rate, Am. J M. *Sc 218 669, 1949*
15 Horwitz, O , Peirce, G , and Montgomery, H Oxygen tension of tissues by the polarographic method III The effect of local heat on the oxygen tension of the skin of extremities, Circulation 4 111, 1951
16 Williams, P G , Montgomery, H , and Horwitz, O Oxygen tension of tissues by the polarographic method VI Effect of changes in position on oxygen tension of the skin of toes, J. Clin Invest. 32 1097, 1953

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Erythermalgia (Erythromelalgia) of the Extremities

Definition: The term "erythromelalgia," which is derived from the three Greek words *erythros* (red), *melos* (extremities), and *algos* (pain), indicates red, painful extremities (S. W. Mitchell, 1878) This term, however, is not entirely adequate because it does not denote the importance of heat. If only redness and pain were necessary for the diagnosis of erythromelalgia, such a diagnosis could be made in many cases of thromboangiitis obliterans or arteriosclerosis obliterans, for in these conditions the feet are commonly red and painful.

A more descriptive term, namely, "erythermalgia," seems appropriate for the syndrome commonly called "erythromelalgia." It is derived from the three Greek words *erythrotes* (redness), *therme* (heat), and *algos** (pain), and therefore comprehends the three important components of the syndrome.[7] Since this new term cannot be applied to what has already been denoted as "erythromelalgia," I have enclosed the word "erythromelalgia" in quotation marks and have used the term "erythermalgia" whenever such usage seemed appropriate

The literature relative to "erythromelalgia" is very confusing. Many cases have been reported as examples of "erythromelalgia" which bear only the slightest resemblance to the condition Part of the confusion results from the fact that in earlier times reliable methods of determining the temperature of the skin were not available and part from the lack of a precise definition, which, as Lewis has pointed out, was evident even in Mitchell's original presentation.

The condition is characterized by burning distress, involving any of the extremities, which is inseparably linked with, and entirely dependent on, elevation of the temperature of the skin of the affected parts. When the temperature of the skin is elevated to or above a certain critical level by

* I have used the term *erythrotes* to designate the discoloration observed in this syndrome It varies widely in intensity in different cases In appearance, it varies from a dusky or cyanotic redness to a light redness Usually it is the least remarkable of the three constituents of the syndrome The term *therme* is used to indicate heat or excessive warmth Although the chief attribute of this term lies in its indication of objective warmth or heat, it may also express subjective warmth or heat. The term *algos* indicates pain of a nonspecific nature which is less tolerable than mere discomfort.

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any means, distress occurs, and when the temperature of the skin is reduced, by any means, to a point below the critical level, the distress disappears. This condition affects otherwise healthy persons who do not have any detectable organic disease of the nervous or vascular systems, and it may therefore be considered a primary disturbance.

Occasionally the syndrome may be associated with hypertension or polycythemia, and it may occur in organic, neurologic, or vascular disease, but under these circumstances it seems to be a secondary manifestation of the organic disease. Whether primary or secondary, however, the syndrome is essentially the same. An analogous situation holds in Raynaud's syndrome, for vasomotor symptoms similar to those observed in Raynaud's disease may occur in thromboangiitis obliterans, arterial thrombosis due to cervical rib, and in a variety of other conditions which do not warrant the designation Raynaud's disease because the vasomotor syndrome is obviously secondary to organic disease. I am not concerned here with Lewis' observation that the syndrome may involve other than the extremities.

Pathologic Physiology.* ***Increased Temperature of the Skin:*** An increase in the temperature of the affected extremity in erythermalgia is invariably accompanied by distress. It makes no difference whether the increase occurs spontaneously or is induced by local application of heat, as by immersing the extremity in warm water, increasing the temperature of the environmental air, or warming the skin by direct contact with a warmed metal bar.

Of all the various disturbances occurring in erythermalgia the increased temperature of the skin is the most important, and it is entirely constant. The temperature at which distress can be produced varies with different individuals and in different parts of the extremity of the same individual. It usually lies within the range from 32° to 36° C. (89.8° to 96.8° F.). Lewis' designation, the "critical point," is an excellent one; it indicates the temperature at which distress occurs. With temperatures higher than this critical point the distress persists, and with temperatures below this critical point the distress disappears. Lewis has justifiably objected to the intimation that increased temperature occurs in episodes indicative of "vasomotor storms," for the increased temperature and hence the distress may be reasonably constant.

Vasodilation: Vasodilation is the commonest cause of the increased temperature of the skin in erythermalgia. It seems to be the direct cause of the attacks of burning distress which occur spontaneously. Vasodilation, however, is only an indirect and not an integral part of the mechanism causing the distress. This is shown by the observation that distress can be induced by warming the skin of an extremity affected with erythermalgia, or it can be maintained in such an extremity when the flow of blood has been brought to a standstill by inflation of a cuff about the extremity to a pressure greater than the systolic blood pressure, provided the warmth of the skin is as great as, or exceeds, the critical point. Evidence of vaso-

* For the purpose of clarity I have simplified this phase of the presentation and intentionally avoided detail.

dilation other than increased temperature of the skin is increased amplitude of arterial pulsation, the throbbing sensations that are frequently mentioned by patients, increased elimination of heat (as shown by calorimetric studies), and increased content of oxygen in the venous blood coming from the extremity.

Hydrostatic Pressure: If the temperature of the skin is just slightly below the critical point, distress may be induced when the intravenous pressure is increased by placing a sphygmomanometer cuff about a proximal joint of the extremity and inflating it to a pressure about the same as the diastolic blood pressure. In addition, distress may be lessened if an extremity is elevated, and accentuated if an extremity is dependent, even if the temperature of the skin remains unchanged The burning distress may be relieved by direct pressure on the skin. I cannot agree with Mufson that the fundamental cause of the distress in erythermalgia is relative hypertension within the minute vessels of the skin, for, if the temperature is suitably increased, distress may be induced in an extremity in which blood flow has been stopped *

Susceptible State of the Skin: It is apparent on even superficial consideration that temperatures of the skin which almost routinely† provoke distress in patients with erythermalgia have no such effect on those without erythermalgia This observation caused Lewis to describe a "sensitive state of the skin." It seems unquestionably true that, for reasons not clearly understood, the skin in erythermalgia is sensitive in an unusual degree to warmth.

Vasoconstriction: In some instances there seems to be unusual vasoconstriction in the extremities between episodes of burning distress. This is shown generally by hypertension in some cases and locally by coldness and cyanosis or pallor of the skin between the episodes of burning.

Nature of the Distress: Mitchell's "pain of a burn," "pain of mustard," and "pain of intense sunburn," are graphic descriptions of the severity and character of the pain. The patient usually states that the distress affects the ball of his foot or the tips of his toes, or the corresponding parts of the hand. However, as one induces distress for purposes of study, it is often described vaguely by the patient as an aching, pricking, sticking, pins-and-needles sensation which may not be localized at all and which may extend up past the ankle or, as it becomes more severe, may reach the knee or even the hip. This type of pain is not burning until the critical level of temperature is exceeded. Moreover, it is fluctuating in type, rising in increasing waves, with shorter and shorter intervals between crests, until it passes from the sticking, pricking type of pain into a definitely burning distress. A modified form of this pricking stage may be noticed as the extremity cools below the critical temperature.

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* By means of inflation of a sphygmomanometer cuff about a proximal joint.

† A "resistant phase" has been noted in patients with erythermalgia. If high temperature of the skin and distress are produced repeatedly, a transient period may be reached in which an increase in the temperature of the skin is not associated with distress.

Diagnosis: A diagnosis of erythermalgia is justified provided there is close correlation between temperature of the skin and the distress. While there may be other manifestations, such as those mentioned in the preceding paragraphs, the dependency of distress on the temperature of the skin is characteristic and pathognomonic of erythermalgia. Sensations of burning in the extremities such as are commonly noted by patients with arteriosclerosis and peripheral neuritis, for example, do not indicate erythermalgia. While close questioning of an intelligent, observing patient who has noted objective absence or presence of increased warmth of the skin when burning distress occurs may allow tentative exclusion or acceptance of the diagnosis of erythermalgia, the final diagnosis must be based upon objective studies.

Methods of Study: In order to demonstrate the essential relationship between skin temperature and distress, it is necessary to increase the temperature of the skin to a value at which distress occurs. This can be accomplished in several ways: (1) Reflex vasodilation can ordinarily be accomplished by means of a baker containing five or six carbon filament lamps so supported that they are about 46 cm. (18 inches) above the skin of the abdomen and chest. A blanket is placed over the baker and the feet are exposed to room air. The temperature of the air within the baker usually is between 50° to 60° C. (122° to 140° F.). Sometimes simply wrapping the extremities in blankets will cause an adequate increase in the temperature of the skin. (2) Direct warmth can be applied by enclosing the extremity within a rough blanket tent, within which a lighted carbon filament bulb is placed. For some reason I have not had much success in producing the distress by immersing the extremity in warm water. The reason for this is not clear. A cylindrical copper bar, about 2.5 cm. (1 inch) in diameter, may be warmed to the desired temperature by immersion in water and applied directly to the skin. Whenever these methods are used, distress is more easily induced when the extremity is dependent. The explanation for this is presented in the paragraph on hydrostatic pressure.

If erythermalgia is present, burning distress occurs as the temperature of the skin increases. Ordinarily, burning occurs when the temperature of the skin is increased to about 32° C. (89.6° F.), and this burning increases in intensity as the temperature of the skin is still further increased. If the mechanism for increasing the temperature of the skin of the extremity is removed and the temperature decreases, the distress disappears. Ordinarily, the critical point of temperature varies less than 1° C. (0.5° F.) in repeated experiments, although different patients have somewhat divergent critical points. If the distress is induced repeatedly, a resistant phase may occur, during which distress cannot be produced even though the temperature of the skin is increased satisfactorily. If the distress is proved to be dependent upon the temperature of the skin, the diagnosis of erythermalgia is established. Confirmatory findings are an increase in the distress when the extremity is dependent or when the venous pressure is raised by means of a sphygmomanometer cuff, and a decrease in the distress when the extremity is elevated or immersed in cold water.

Case Report: A white man, a foreman of underground construction in a gold mine, aged thirty-one years, registered at The Mayo Clinic in September, 1937 In February, 1936, a falling rock had caused a chip fracture of the bone of the left great toe, from which recovery was prompt. In January, 1937, for a short time pain in the left great toe and foot, associated with some swelling of the foot, caused limping. The patient felt that the resultant distress was not the same as that which he had experienced subsequently In July, 1937, this latter type of distress, which will be described subsequently, appeared, and as a result the fragment of bone was removed from the left great toe Relief was not experienced except while the patient was in bed

From the time of onset in July, 1937, to the time of the patient's admission to the clinic, he had experienced eight attacks of distress, each of which lasted three or four days At first, only the left great toe was involved, but in the last two attacks the discomfort spread to the ball of the foot and the fifth toe This distress was described as "hot, burning, throbbing, aching and pulsating" in nature. It seemed to be precipitated and aggravated by work, walking or climbing *Relief was obtained constantly but transiently by rest, elevation, and cold* water. Some medicine, which the patient believed to be sodium salicylate, had not helped Because of the distress the patient was forced into a sedentary occupation. While he was driving to Rochester he discovered that ten grains of acetylsalicylic acid (aspirin) produced prompt relief, which persisted for about three days He had noted increased surface temperature, red to deep purplish discoloration, and increased sweating of the foot during episodes of distress

Physical examination and routine laboratory tests gave negative results The peripheral arteries pulsated normally The percentage volume of cells in the blood (hematocrit) was 53 0.

The patient lay on a bed in a room which was kept at a constant temperature, fully clothed except that his shoes were removed, for forty minutes His socks were removed at 1:55 P.M. and he lay with his feet exposed until 2 25 (Table 1). No distress was noted. At 2 25 he sat on the edge of the bed with both feet dependent. Distress of a "throbbing" type involved the left first toe and the outer side of the left foot in about twenty-five seconds The temperature of the left foot increased rapidly, and, as it did so, "aching," "burning," and "soreness" occurred in the distal half of the foot. Changes in the temperature of the skin of the right foot were minimal (Table 1) On a subsequent day, during an episode of spontaneous distress associated with an elevated skin temperature, the patient was given ten grains of acetylsalicylic acid by mouth. Complete relief was experienced in twenty minutes, although the skin temperature was not influenced by the drug. It was also shown that immersion of the foot in cold water gave immediate relief. Additional studies showed that vasodilation was more easily induced in the afflicted areas than elsewhere. When both feet were wrapped loosely in a blanket, within which heat was produced by a carbon filament bulb, the temperature of the skin of the left first and third toes and of the ball of the foot increased more rapidly than did that of corresponding areas of the right foot (Table 2). This procedure, carried out two or three days after the patient had ingested aspirin, did not produce distress even though the temperature of the skin was high

These observations seem to be important. As expected, there was a close relationship between the distress and the temperature of the skin. The critical point was from about 31.0° to 32.0° C. (87.8° to 89.6° F.). Most surprising was the marked increase in the temperature of the skin of the

TABLE 1
Temperature Studies

Time P.M.	Left foot: First Toe	Left foot: Third Toe	Left foot: Fifth Toe	Left foot: Ball of Foot	Right foot: First Toe	Right foot: Third Toe	Right foot: Fifth Toe	Right foot: Ball of Foot	Room Temp. degrees C.
	Temperatures in degrees C.								
2:05	30.4	31.2	30.1	33.8	28.2	29.2	30.5	30.9	24.7
2:25	30.5	31.4	30.7	33.7	27.1	28.9	29.7	30.4	24.3
2:27	31.2*	31.9	31.1	34.1*	27.1	29.0	30.1	30.4	24.1
2:35	32.4*	34.0*	31.9*	34.8*	27.7	29.8	30.7	30.3	23.7
2:41	32.6*	34.6*	33.2*	35.1*	29.3	30.3	31.2	30.5	24.6
2:55	32.3*	34.2*	32.2	35.4*	30.3	29.8	31.0	30.8	23.9

* The designation (*) indicates the presence of distress

TABLE 2
Temperature Studies

Time A.M.	Left foot: First Toe	Left foot: Third Toe	Left foot: Ball of Foot	Right foot: First Toe	Right foot: Third Toe	Right foot: Ball of Foot	Room Temp degrees C.	Comment
	Temperatures in degrees C.							
9:30	23.8	23.2	24.6	23.4	23.1	24.3	23.4	Patient recumbent
9:40	23.8	23.1	24.6	23.3	23.1	24.2	24.3	Patient recumbent
9:42	23.8	23.2	24.6	23.3	23.1	24.2	24.1	Patient sitting; feet wrapped in blanket
10:30	25.4	24.2	25.6	23.4	23.4	24.3	24.0	Patient sitting, feet wrapped in blanket
10:47	29.4	26.3	27.5	23.9	23.4	24.4	24.4	Heat applied to blanket
11:15	32.7	32.0	32.2	24.2	23.5	24.7	24.0	Heat in blanket
11:35	36.9	33.0	34.5	31.5	27.5	28.8	24.2	Heat in blanket
11:45	38.1	33.9	35.0	35.4	35.5	30.3	24.0	Heat removed
11:50	36.0	33.2	34.9	35.0	29.0	30.6	23.9	Heat removed
12:00	35.1	34.0	34.8	32.8	28.8	30.7	24.0	Heat removed

left foot as a result of dependency alone; in contrast, there was very little change in the temperature of the right foot. Noteworthy also was the prompt relief following the administration of acetylsalicylic acid.

Treatment: The treatment of erythermalgia is not uniformly successful, and the therapeutic result depends more on the severity of the condition than on therapeutic measures. The more severe the syndrome the less

likely it is that a satisfactory therapeutic result will be obtained It is important to exclude any primary cause for erythermalgia, and if such is present, treatment should be directed at the causative disease. For example, successful treatment of polycythemia vera frequently results in cessation or decrease of attacks of associated erythermalgia.

The basic treatment of essential erythermalgia consists of (1) the avoidance of an environmental temperature that is sufficiently warm to provoke an episode of the disease, (2) the use of a cold environment (local or general) to bring about cessation of an acute episode, (3) the use of acetylsalicylic acid to alleviate symptoms and (4) the use of vasoconstrictive drugs as prophylaxis against acute episodes

The relationship of warm environment and critical temperature to the precipitation of acute episodes of erythermalgia has been discussed. Obviously, patients afflicted with this syndrome should attempt to avoid an environmental temperature that is sufficiently warm to provoke an attack. Milder forms of the disease may be relatively easily controlled in this manner. However, rigid control of one's environmental temperature so as to avoid "critical" warmth at all times is rarely possible. Thus, prevention of episodes of erythermalgia by control of environmental temperature is rarely completely successful, and this is particularly true in the more severe form of the disease. Patients with erythermalgia may be helped by a moderate climate or by use of air conditioning to control their environmental temperature. Use of open sandals with or without lightweight hose may help to prevent attacks

During an attack, patients can obtain prompt relief by the local use of cold (immersing affected extremities in cool or cold water, or placing them on a cold object) or by exposing themselves to a cold environment (air-conditioned room, cool outside air). Most patients with erythermalgia discover this fact themselves.

Acetylsalicylic acid in small or average doses (0.65 Gm. [10 grains] one to four times daily) often may be highly successful in preventing acute episodes of erythermalgia. On occasion my colleagues and I have noted relief from symptoms for several days after ingestion of only 0 65 Gm. of this drug at one time. No adequate explanation of this is available but it is so common that we have learned to suspect erythermalgia when patients mention marked and prolonged relief of symptoms as a result of ingestion of acetylsalicylic acid.

Several vasoconstrictive drugs have been used in the treatment of erythermalgia, including epinephrine, norepinephrine, ephedrine, and kutapressin (a substance isolated from liver extract). Although an occasional patient may respond favorably temporarily to one or more of these drugs, in general they rarely are significantly beneficial. However, it is reasonable to try vasoconstrictive agents, because an occasional patient may obtain some relief from symptoms

Other forms of treatment used in the past, but rarely, if ever, used at present, include radiation therapy, histamine desensitization, administration of antihistamine agents, attempts at desensitization of the skin to warmth, and section, crushing, or alcohol injection of peripheral nerves supplying the affected extremities.

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Lymphedema of the Extremities

Etiology: Lymphedema, which affects human beings, appears to have a multiple etiology. The mechanism of its production, which is, however, apparently the same in all cases, is predicated on clinical and experimental observations.[1,2,3] Lymph stasis occurs primarily as a result of obstruction that is produced by inflammatory or noninflammatory processes, or by lymphangiectasis, which occurs in association with congenital lymphedema.

CLASSIFICATION OF 300 CASES OF LYMPHEDEMA

	CASES
A Noninflammatory:	
I Primary	
Precox	93
Congenital	
1. Simple	12
2 Familial (Milroy's disease)	0
II. Secondary:	
Malignant occlusion	32
Surgical removal of lymph nodes	61
Pressure	1
Roentgen and radium therapy	3
B. Inflammatory:	
I. Primary (single or recurrent acute and chronic)	41
II. Secondary (single or recurrent acute and chronic):	
Venous stasis	13
Trichophytosis	5
Systemic diseases	5
Local tissue injury or inflammation	33
Filariasis	1

When obstruction occurs, the intralymphatic pressure increases, and causes dilation of lymph vessels with subsequent insufficiency of the valves, forcing lymph to seek new channels which are supplied inadequately with valves. Since valves are very important in causing the lymph to move centrally, incompetence of the valves causes further stasis of lymph. The protein content of the lymph increases and fibroblasts proliferate rapidly since the lymph is an excellent culture medium for the growth of fibroblasts. This fibrosis contributes further to lymph stasis. As a result of the increased quantity of lymph in the tissues, attacks of acute inflammation may recur, producing thrombosis of lymph vessels, more stasis of lymph and, hence, more fibrosis. The cycle, which is a vicious one, consists of stasis of lymph, fibrosis, inflammation with further stasis and, hence, more fibrosis.

NONINFLAMMATORY LYMPHEDEMA

Primary Lymphedema*: "Lymphedema precox" is an original term applied to a definite clinical syndrome manifested in ninety-three cases in the group of 300 cases studied. It affected female patients predominantly (eighty-seven per cent of the cases), and in the majority of instances (sixty-five per cent) had its onset between the ages of ten and twenty-four years, inclusively. The term "precox" is used to denote an early development; in many of the cases in this group the onset of symptoms occurred at puberty, and the incidence of onset in adolescence was impressive.

The swelling occurs spontaneously and without known cause; at the onset the patient ordinarily notices a puffiness about the foot or ankle. The edema is worse during long periods of activity, during the menses, and in warm weather. Rest in bed and elevation of the extremity produce temporary disappearance of the edema that may affect one lower extremity exclusively (seventy per cent in this series) or both legs simultaneously, one extremity may swell months or years after the opposite member has become involved.

The edema ordinarily progresses up the leg slowly, and eventually the entire limb becomes edematous over a period of months or years. The spread of the edema may, however, be much more rapid; the entire limb may be involved within a few days or weeks. In many instances, swelling is limited to the foot and ankle or does not extend above the knee. Frequently, this particular state is doubtless merely a phase of a progressive condition, but in other instances it seems to represent the maximal degree of extension of the edema.

Gradually the swelling, whatever its limitations, becomes more marked; elevation and rest in bed cause its reduction but not its disappearance. The smooth skin becomes roughened, and the hitherto soft edema becomes resistant to pressure. In addition to enlargement of the limb due to edema, there is actual hypertrophy of tissue, and the limb becomes unsightly, ungainly, and uncomfortable. A dull, heavy sensation is present, but there is no actual pain.

The entire course of the swelling is ordinarily one of smooth progression; acute lymphangitis and cellulitis occur infrequently (in thirteen per cent of the cases studied). Ulceration of the skin does not occur. The entire history is ordinarily that of conversion of a normal limb into a swollen one; nothing else is noteworthy.

The cause of lymphedema precox is obscure. The predominant incidence among female patients, the onset in the majority of cases during adolescence, and the accentuation during menstruation tend to indicate that the reproductive organs play a part in the condition. Possibly the additional load thrown on the lymph vessels by rapidly developing reproductive structures induces a functional incompetence of the lymph vessels or allows entrance of infection into the lymph trunks and nodes in the pelvis Even minor degrees of functional inadequacy, through obstruction in the pelvis, might lead to dilatation of the lymph vessels below, with incompe-

* This designation indicates noninflammatory type of lymphedema

tence of the valves, particularly among women, whose subcutaneous tissues offer little support. The resulting interference with the free passage of tissue fluid into the lymph vessels provides adequate encouragement for the growth of fibroblasts and further obstruction by connective tissue. Homans, Drinker, and Field reported a case in which the lymphedema apparently was of the precox type. At exploration, greatly enlarged lymph vessels were found in the pelvis, this was an indication of obstruction proximally. It is possible that the entire explanation rests on a congenital underdevelopment of lymph vessels, or their inability to develop quickly enough to supply adequately tissues that are growing rapidly Limitation of the disease to the lower extremities is striking, and it indicates that gravity is an important factor in the development

ILLUSTRATIVE CASE: A Jewess, thirty-two years old, was admitted to the clinic complaining of a swollen right extremity This swelling, which had appeared one year previously in the region of the ankle, had gradually progressed until the entire extremity from the dorsum of the foot to the inguinal region had become involved. During the first few months the swelling had fluctuated in degree, but in the six months preceding admission it had remained relatively stationary, although elevation of the leg for any prolonged period had reduced the size somewhat. There was no associated pain and no history of any preceding trauma or infection.

On examination at the clinic, the right leg was found to be about half again as large as the left, pitting edema of the dorsum of the right foot, right leg, and right thigh being present There was no evidence of disease of the kidneys, heart, or pelvic structures Fissures were present between the toes, but trichophytes could not be demonstrated microscopically A Kondoleon type of operation was advised but the patient refused Adequate supportive bandaging was therefore recommended after elevation of the limb until there had been maximum reduction in the size of the limb

Congenital Lymphedema*: This may be either simple or familial In both types, lymphedematous swelling, usually of one lower extremity, is present at birth. There may be actual hypertrophy of the limb which is the result of fibrous hypertrophy In other instances, the skin is soft, and the edema is less resistant to pressure. The two forms do not vary, except that in the simple type blood relatives are not similarly affected In the familial type several persons in the same family have lymphedematous swellings of one or more extremities. The familial type, known as Milroy's disease, was first described by him as a clinical entity in 1892

Secondary Lymphedema*: This may be the result of malignant occlusion of lymph vessels by metastasis of malignant disease of the breast, uterine cervix, uterus, vulva, prostate gland, bladder, testes, skin, or bones to adjacent lymph nodes. *Such a possibility serves to emphasize the necessity of close scrutiny for evidence of malignant disease in all cases of lymphedema*, since swelling may be the first outward manifestation. Pressure outside the lymphatic trunks perhaps occasionally, but rarely, produces lymphedema. The one case of lymphedema apparently due to pressure in this series seemed to follow the use of a truss for inguinal hernia

* This designation indicates noninflammatory type of lymphedema

Secondary noninflammatory lymphedema may occur in cases of Hodgkin's disease, or lymphosarcoma, or it may be associated with multiple hemorrhagic sarcoma, which has been described by Kaposi; or it may follow surgical removal of lymph nodes and lymph vessels for malignant disease distally situated, or for tuberculosis or metastasis of malignant disease. The last-named condition is the elephantiasis chirurgica of Halsted. Such a condition is not uncommonly seen following radical amputation of the breast and the removal of the axillary lymph nodes for carcinoma. The lymphedema may occur with or without intercurrent attacks of lymphangitis and cellulitis. The irregular interval at which lymphedema occurs after radical amputation of the breast is remarkable. Usually, the arm begins to swell on resumption of activity, but weeks, months, or even years may pass before the extremity becomes edematous. In one instance, the arm was free from swelling for 9½ years; there was no evidence of the recurrence of malignancy to account for the edema, and cellulitis and lymphangitis had not occurred. In such instances, it is possible that fibrosis may be induced by repeated irradiation, thus producing lymphatic obstruction, or, that occult lymphedema, which has been present for years, has resulted in overgrowth of connective tissue and obvious edema. Lymphedema may occur after treatment with radium and roentgen rays. Whether such a result is brought about by the fibrosis caused by irradiation or by metastasis of the malignant disease for which radiation is given cannot be determined with certainty.

INFLAMMATORY LYMPHEDEMA

General Characteristics: The advanced stage of inflammatory lymphedema has been called "elephantiasis nostras streptogenes." All examples of inflammatory lymphedema, exclusive of the chronic form, have one feature in common, single or recurrent attacks of acute cellulitis and lymphangitis. The contrast between lymphedema of inflammatory origin and of the precox type is striking; in the former, progression is by a series of attacks which are impressive in the suddenness of onset, and striking in the severity of systemic reaction; in the latter, the history is one of slowly progressive edema. The usual victim of an attack of cellulitis and lymphangitis of an advanced grade is suddenly seized with a severe chill unpreceded by other symptoms, or, following a short period of distress in the extremity or in its proximal lymph nodes, his teeth chatter, the bed shakes, and he becomes nauseated and vomits. His temperature is between 38.3° and 41.1° C. (101° and 106° F.); in a short time a small, reddened area spreads until a considerable portion of the extremity is swollen, red, hot, and tender. The proximal lymph nodes are tender and swollen. The chills recur during a period of thirty minutes to an hour. The high fever persists for a period ranging from a few hours to two or three days, and is accompanied by marked malaise that may persist after the temperature returns to normal. The abnormal condition of the extremity recedes slowly over a period of from four to fourteen days, but, after all clinical signs of acute inflammation have disappeared, swelling is present in a greater degree than before the attack. The organism chiefly responsi-

ble for the attacks of acute inflammation is the streptococcus Single attacks leave minor degrees of lymphedema, but successive attacks, which tend to occur progressively more frequently produce increasing edema; each attack is a step toward the final stage, namely, marked lymphedema

The chronic form of lymphangitis of the spontaneous inflammatory type is exceedingly rare. In such instances, the leg is persistently warmer than its companion member, and a reddish discoloration of the skin exists In many instances, lymphedema following injury or infection develops without the intervention of acute attacks of lymphangitis and cellulitis or of clinical manifestations of chronic lymphangitis. The infection in such instances is considered to be subclinical. It should be emphasized that lymphangitis, whatever its nature, produces occlusion of lymph vessels by thrombosis which produces lymph stasis which in turn provokes further fibrosis and more stasis of lymph

Primary Lymphedema*: This term signifies a condition resulting from single or recurring acute attacks or from chronic lymphangitis and cellulitis not secondary to any known local abnormality, such as venous or lymphatic stasis or extraneous infection. In many such instances the lymphangitis appears to occur in much the same spontaneous manner as tonsillitis or phlebitis. In other instances it may be due to infections introduced into the lymph vessels through minor portals of entry unnoticed by the patient. The acute attacks of lymphangitis and cellulitis have been described; each attack leaves a residue of increased edema. In the chronic form of lymphangitis the edema is slowly progressive.

Secondary Lymphedema*: This term indicates a condition resulting from lymphangitis secondary to known causes The lymphangitis may occur in single or recurrent attacks or in a chronic form. Chronic edema of venous origin may predispose to recurrent attacks of acute cellulitis and lymphangitis, and thus to progressive lymphedema, but such instances are uncommon, in light of the rather common occurrence of thrombophlebitis resulting in edema.

Trichophytosis about the toes may induce recurrent attacks of acute lymphangitis. The inflammation and the resultant edema are ordinarily limited to the foot and ankle. It is probable that an etiologic relationship exists in but a small percentage of instances in which trichophytosis and acute attacks of lymphangitis occur in the same patient. It is not clear whether the trichophytes themselves or secondary bacterial invaders are responsible, even when the trichophytic infection seems to be definitely related to the acute inflammatory attacks. Instances which strongly suggest that the Trichophyton is directly or indirectly responsible for the acute attacks are those in which marked evidence of trichophytic infections, such as desquamation and the occurrence of vesicles, precedes the appearance of cellulitis and lymphangitis. Pregnancy and systemic diseases, such as influenza, typhoid fever, pneumonia, malaria, and filariasis, may lead to recurrent attacks of cellulitis and lymphangitis and result in lymphedema. Except in cases of filariasis, it is possible that the original

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* This designation indicates inflammatory type of lymphedema

lesion is a thrombophlebitis that produces lymphatic as well as venous occlusion. Occasionally, conversion into the lymphedematous state proceeds without the intervention of attacks of acute inflammation; in such instances it is assumed that a condition of chronic lymphangitis exists or that the lymph vessels become obstructed by overgrowth of connective tissue, which is, in turn, a reaction to stasis of tissue fluid. Tissue fluid acts as an excellent culture medium; fibroblasts grow and fibrosis results unless the blood plasma is promptly returned to tubes lined with endothelium.

Local inflammation or injury of tissue most commonly leads to the production of lymphedema through the intermediation of single or recurrent attacks of lymphangitis or chronic lymphangitis. In the cases studied, such diverse causes as contusions, lacerations, surgical incisions, vesicles, abscesses, furuncles, burns, fractures, penetrating wounds, bites by dogs, tularemic abscesses, pelvic inflammatory diseases, and appendicitis were directly responsible. The acute attacks may occur weeks or months after the original trauma, which may not be associated with any marked clinical evidence of infection. Some stasis of lymph, subclinical in degree or unnoted by the patient, seems to exist; then, for some unknown reason, marked bacterial activity occurs, and an acute attack of cellulitis and lymphangitis is clinically apparent. It seems strange that minor abrasions should allow entrance of infection into the tissues, but the slightest wound of the corium may tear lymph vessels open and permit material to enter them directly. In many instances, the lymphedema occurred following injury or infection without the intervention of acute attacks of inflammation, and seemed to be caused by chronic or subclinical inflammation and thrombosis of lymph vessels, or by minimal lymph stasis which provokes connective tissue overgrowth.

Illustrative Case: An infantry captain, thirty-three years of age, was admitted to the clinic June 1, 1936, complaining of a swollen right leg In April, 1934, a horse had fallen on him, causing fracture of the right wing of the sacrum and separation of the symphysis pubis He was treated in a hospital for six weeks with traction and a splint. Shortly afterward, while walking with the aid of crutches, he noticed swelling of his right leg and ankle. In August, 1934, following an operation for ingrown toenail, chills and fever occurred and there was evidence of acute cellulitis and lymphangitis, which left a residual swelling of the right ankle and foot. In September, 1935, following exposure in a rainstorm, a second similar attack occurred Since that time he had had six additional episodes of acute lymphangitis and cellulitis, characterized by chills and fever, prostration, and redness and increased warmth of the right leg Following each attack, the swelling of his right leg had increased

On examination at the clinic, there was massive swelling, with some pitting edema, of the entire right leg, from the toes to the groin The skin was thickened and brawny with a reddish, shiny coloration. There was no evidence of cardiac or renal disease. The tissue between the toes was macerated and microscopic examination revealed trichophytes. The Kondoleon type of operation was recommended but the patient remained undecided He was instructed as to adequate bandaging.

In this case it appeared that fracture of the pelvis had produced some lymphatic obstruction and lymphedema Subsequently, recurrent episodes of

acute lymphangitis and cellulitis occurred which were probably, but not certainly, due to trichophytes Each episode of inflammation increased lymphatic block and caused more fibrosis

DIFFERENTIAL DIAGNOSIS

There is rarely any difficulty in distinguishing advanced lymphedema from edema due to other causes. The brawny indurated skin and the hypertrophied limb of lymphedema bear little resemblance to manifestations of edema in other diseases. It is only when the lymphedema is not associated with changes in the appearance and feel of the skin that difficulty arises. Lymphedema can be distinguished without difficulty from the edema of general systemic diseases, such as myxedema, myocardial failure, nephrosis, nephritis or deficient proteinemia, when it is unilateral, when it is bilateral, a thorough examination is necessary to exclude these diseases. Sarcomas, lipomas, and neoplasms of the bone are almost uniformly unilateral, and they produce regional or localized swellings, whereas the edema of lymphatic obstruction is more uniform and extensive When swelling of an extremity is localized, careful roentgenologic studies are invaluable from a diagnostic standpoint. Angioneurotic and cyclic edemas are characterized by this intermittence, whereas lymphedema is more constant and disappears during the early phase only on elevation of the limb, well-advanced lymphedema responds to this procedure incompletely. Enlargement of a limb in arteriovenous fistula is associated with dilatation of and increased pressure in the regional veins; analysis of the blood from these veins reveals an oxygen content approaching that of arterial blood. If the arteriovenous fistula is congenital, or was acquired before longitudinal growth of the bones ceased spontaneously, the limb is increased in length as well as in circumference. All these signs of arteriovenous fistula, except the increased circumference of the limb, are absent in lymphedema.

The edema of limbs occasionally noted in lymphosarcoma is probably of lymphatic origin, but recognition of the basic condition is important. Ordinarily, in cases of lymphosarcoma, there are enlarged nodes in the regions in which nodes are usually palpable, and in the mediastinum. Microscopic examination of a node removed surgically is invaluable when doubt exists. It may be remarked parenthetically that it is always important to examine patients with lymphedema carefully for evidence of malignancy. Lipodystrophy, characterized by "fat legs," is to be distinguished from lymphedema. Young women and girls with lipodystrophy are subject to worry, anxiety and even to embarrassment at the supposed cosmetic disfiguration. Such reactions have arisen largely as a result of short dresses and hosiery advertisements, for aside from a slight disturbance in the symmetry of the body, no disfiguration exists. The condition, however, is as important as it appears to the patients The characteristic symptoms which lymphedema and lipodystrophy may have in common are predilection for women, similarity in appearance, painlessness, and additional swelling of the feet or ankles when patients are on their feet much, particularly in warm weather. Lipodystrophy is uniformly bilateral, and is usually associated with generalized obesity or obesity about the pelvis. The degree, but not the extent, of lipodystrophy may progress after it is first noted. In

contrast, lymphedema is usually unilateral, not ordinarily associated with obesity and usually progresses from the foot proximally, except when it is congenital. Attacks of lymphangitis and cellulitis may occur in lymphedema but not in lipodystrophy. Pitting on pressure may occur in both conditions, but it is less evident in lipodystrophy. The diminution in size, which may follow elevation of the extremities in both conditions, is more marked in lymphedema.

The edema of deep thrombophlebitis is usually to be distinguished from lymphedema because the former is similar to lymphedema in so many respects. Well advanced stages of either condition offer little difficulty in diagnosis. The hypertrophied limb, with the thickened skin and firm consistency, characteristic of lymphedema, has little similarity to the limb in cases of deep thrombophlebitis, for the latter is marked by softer edema, stasis ulcers, dermatitis and superficial varices. To be sure, when attacks of recurrent lymphangitis or cellulitis occur, the leg that was originally edematous from venous obstruction acquires an additional element of lymphedema, and lymphedema may occur around varicose ulcers as a result of chronic infection. However, pure uncomplicated lymphedema, whatever its origin, does not lead to ulceration.

It is in the earlier phases of the two diseases that difficulty is encountered; the usual similarity of symptoms includes unilaterality, pitting on pressure, normal skin texture and disappearance of edema following elevation of the limb. Dissimilarities exist in the circumstances of origin, speed of onset and progress, distress experienced by the patient and condition of the superficial veins. Thrombophlebitis with edema usually occurs in the course of or following an illness such as pneumonia or typhoid fever, or follows childbirth or operation. During the acute stage, a dull aching distress occurs in the area of the involved vein, which is tender to pressure; the edema develops rapidly to its fullest extent in the course of hours, and the superficial veins are dilated. Lymphedema does not ordinarily occur during systemic disease. The absence of distress is striking, except when acute cellulitis and lymphangitis occur; the edema ordinarily develops to its fullest extent slowly over a period of weeks, months or years, and the superficial veins are not dilated.

Among dissimilarities, the localized distress that occurs in thrombophlebitis is most important. Occasionally, the two conditions may coexist, as in the case of the thrombophlebitic limb that is involved in recurrent attacks of lymphangitis and cellulitis. In rare instances it may be difficult, if not impossible, to distinguish between the two conditions, although roentgenologic studies may be of some value. The difficulty is particularly great when patients can relate only vague details about the development of the edema.

MEDICAL TREATMENT

Medical treatment, in order to be of value, must be carried out early. There is no medical treatment of value when the limb is greatly hypertrophied from the overgrowth of connective tissue. Treatment must be instituted when the edema first becomes evident. The longer uncontrolled lymphedema exists, the more fibrosis occurs, and the less efficient medical

treatment becomes. This point needs to be emphasized, for most patients seen at The Mayo Clinic who have lymphedema have had it for a long time, and marked fibrosis, which cannot be influenced by medical treatment, has already occurred.

Control of Edema: The rationale of attempting to control edema is based on a conception of the condition within the tissues Large lymphatic spaces exist, valves are absent or are functionless as a result of dilation of the lymph vessels, and lymph, which ordinarily moves proximally as a result of muscular activity and the action of valves, is static, or flows to dependent parts. A close parallelism exists with the condition present in varicose veins. The problem is one of causing the lymph to move toward the body by preventing stasis. We know of no way to accomplish this medically, other than by compressing the limb by adequate bandaging

An important first step is elevation of the extremity until as much as possible of the lymph has been removed from the extremity. Cloth bandages are of little or no value; the support which they give is of little value. Elastic stockings are unsatisfactory in many instances, for the same reason; they tend to stretch and lose their elasticity. Adhesive bandages are somewhat more efficient than the previously mentioned supports.

The entire criteria for establishing the value of any type of support is control of edema; a support which does not prevent swelling, when the patient is active, is valueless; one which prevents swelling is adequate. I prefer a pure rubber roller bandage, three inches wide and fifteen feet long Of the three weights available, the proper one prescribed for any specific patient depends on the difficulty in controlling the edema. Ordinarily, the bandage is applied over a lisle stocking, beginning by making two turns about the foot, two figure-of-eight turns about the ankle, and progressing up the extremity to the knee. The toes and part of the heel are left exposed. The bandage should be removed and applied in the same manner each time, as it becomes shaped to the extremity on repeated use If it is applied too tightly, the toes become discolored, cold and numb If it is applied too loosely, edema results Patients soon become adept at bandaging their legs efficiently. The bandage should be removed at mid-day and reapplied over a dry stocking after the patient has rested for an hour.

The same procedure is repeated at night if the patient is active. If he remains home, he may remove the bandage and elevate the leg, while sitting. Patients object to wearing the bandages because of the inconvenience in applying them repeatedly, the slight discomfort, and their unsightly appearance. This is particularly true of women, who object to the appearance of the bandaged limb Frequently, a well-fitting elastic stocking may be used for "dress" occasions and the use of the heavier rubber bandage may be reserved for ordinary activity It is well to point out to women that the lymphedematous leg has an abnormal appearance which the bandage increases but little, and to emphasize that uncontrolled edema almost invariably causes a gradual increase in the size of the limb. I have no information regarding how long the bandage should be worn; in some instances, it must be used indefinitely; in others, improvement in circulation of the

lymph may occur. Once every month or so, the bandage can be left off for a day as a trial. If edema reappears, the support must be worn again.

Treatment and Prevention of Inflammation: The attacks of acute lymphangitis ordinarily subside spontaneously, but recovery appears to be hastened by elevation of the limb and by the application of hot moist packs. When reactions are severe, streptococcus antitoxins, such as those which are used in the treatment of erysipelas or scarlet fever, or polyvalent serums may be used. Blood serum from patients who recently have recovered from an attack of acute lymphangitis and cellulitis may be of value. I have never observed patients to whom I thought it necessary to give antitoxins or convalescent serum for an episode of acute inflammation. Sulfanilamide may hasten recovery.

Almost the entire problem, as far as infection is concerned, is the prevention of attacks. Unfortunately, we have no proved way of accomplishing this. I have felt that some commercial preparations, such as streptobacterin, when administered for a long period have been helpful but I can offer no direct evidence. More logical would be the manufacture of an autogenous vaccine from organisms which have been isolated from the tissues at the beginning of the attacks. Again, we have no definite evidence that organisms can be isolated regularly during attacks or that a vaccine would be effective in preventing them. I hope that studies with animals which have lymphedema will demonstrate the value of this method. The periodic injection of a therapeutic amount of streptococcus antiserum every few weeks may be of value. Care should be taken to avoid serum reactions. Sulfanilamide may be used intermittently if attacks occur frequently Portals of entry, such as are present between the toes in the presence of trichophytosis, should be removed. When attacks of acute inflammation recur, trichophytosis should always be suspected and vigorously treated, if present.

SURGICAL TREATMENT

The necessity of surgical treatment of lymphedema is a frank admission of failure of medical treatment in those instances in which the best medical treatment has been carried out. In many instances, however, surgical treatment is necessary because medical treatment has been carried out inefficiently or not at all. Selection of cases of lymphedema for surgical treatment depends on the etiology and severity of the lesion. There is no need to perform the operation in cases in which malignancy exists or in cases in which causative conditions of greater importance than lymphedema, such as Hodgkin's disease or pelvic tumors, are present. Unfortunately, we cannot promise the patient who has mild lymphedema a great deal of benefit. The leg can be restored to normal size and to nearly normal shape, but there is no assurance that such restoration will be in any way permanent unless an adequate type of supporting bandage is worn for an indefinite period. Therefore, the more severe the case, the more one can offer in the way of relief with surgical treatment. The history of attacks of cellulitis is not a contraindication to surgical treatment, but on the other hand, one can reasonably assure patients who have had recurrent attacks

of cellulitis that the frequency of these attacks will be reduced. One should, of course, not operate during an attack of cellulitis.

The immediate preoperative care of the patient should consist of rest in bed for a few days, with the affected limb elevated continuously to reduce the edema. A sling, which supports the limb at an angle of at least forty-five degrees, should be used Diuretics, such as salyrgan, and firm bandaging may hasten the disappearance of edema. In three to six days, as a rule, the amount of lymph in the limb will be minimal which will make the surgical procedure much easier than it would have been before. The various surgical methods which have been used for the treatment of lymphedema have been reviewed by Ghormley and Overton. The procedure used at the clinic is that which was described originally by Kondoleon and modified by Sistrunk.

The actual operation should be carried out under spinal anesthesia, using a tourniquet, applied as high as possible on the affected limb and usually without the customary towel beneath it. Two incisions are made along one side of the thigh or arm, extending as high as the lymphedema, so that a long strip of skin may be excised in an elliptical manner. The amount of tissue that can be removed will depend on the width of the strip of skin between the two incisions. As much as possible should be removed in order to reduce the size of the extremity greatly.

When the incisions have been made through the skin the margins of skin to be left are undermined for a distance on either side, approximately half of the circumference of the extremity. The skin, subcutaneous tissue, and as much as possible of fascia, except that at the intermuscular septa and at joint capsules, are removed in one piece. Care should be taken not to damage the main cutaneous nerves. After removal of the tissue, the wound should be closed with interrupted sutures No attempt is made to secure hemostasis, only the larger branches of the veins being ligated.

In closing the wound, one should not hesitate to apply as much tension as is necessary; considerable tension may be applied without fear of sloughing. Indeed, it is better to have some tension than to have an excess of skin remaining redundant. A pressure bandage is applied and the tourniquet released slowly, taking several minutes to allow the circulation actually to return to normal We believe this step to be of considerable importance as it is possible that the sudden flooding of the circulation with material from the large wound may have had something to do with the high incidence of surgical shock. The limbs are not elevated after the operation, so that materials from the wound get into the general circulation somewhat more slowly than if the limbs were elevated. Apparently, as a result of the methods mentioned, the incidence of postoperative shock in these cases has been reduced to almost zero.

After ten days the dressing is changed, and if healing has advanced sufficiently, the patient is allowed to be up. Adequate bandaging, such as that described with the medical treatment, is necessary for an indefinite period. Crutches or cane are unnecessary when the patient resumes walking.

It is customary to wait from three to six months between operations. That is to say, we treat one side of an extremity and allow healing to

become complete before operating on the other side. Occasionally patients get enough improvement from the operation on one side to justify omitting the second stage, but, as a rule, a much better result will be obtained if both sides are subjected to operative treatment.

Ghormley and Overton have reviewed the results in sixty-four cases of lymphedema, in which the condition was treated surgically in the past ten years. In forty-one of these cases there was improvement of varying degrees; no improvement was noted in eight cases; in six cases the patients had died and in nine cases the patients had not been traced.

Recurrent infection such as cellulitis and lymphangitis, which had been present in twenty-five instances preoperatively, was worse after operation than it had been before, in six cases; was improved in nine cases; and had disappeared in eleven instances, as a result of the operation.

There is considerable doubt that the benefit, which follows, results from that effect which Kondoleon originally intended; namely, anastomosis of the superficial and deep lymphatics, if, indeed, this actually occurs. Since the obstruction in many instances appears to be in the lymphatic vessels within the pelvis, little or no benefit would follow the shunting of lymph flow into the deep vessels in the leg, as these are continuous with the obstructed lymph vessels. The operation appears to me to be predominantly a plastic procedure, removing large valveless lymph spaces and hypertrophied connective tissue. As such, it is not a physiologic procedure but simply a plastic one, which corrects deformity. Since lymphedema has been produced experimentally, it is to be hoped that better methods of surgical treatment will be discovered. Perhaps the most satisfactory procedure will be found to be a combination of the plastic operation of Kondoleon, and one designed to carry the lymph around the area of obstruction, such as anastomosis of the lymphatic vessels of the extremity with those of the trunk. Such a procedure as the latter has been described by Gillies and Fraser. Other operations have been described by Homans and by Macey. Ochsner and associates have reviewed the entire subject of lymphedema.

REFERENCES

1. Allen, E V : Arch Int Med 54:606 (Oct) 1934.
2. Allen, E. [illegible] 516 (Nov) 1935
3. Drinker, [illegible] Lymph and Tissue Fluid, Williams and [illegible]
4. Ghormley, R. K., and Overton, L M.: Surg , Gynec , and Obst 61:83 (July) 1935; Proc Staff Meet , Mayo Clin 9:564 (Sept. 19) 1934
5. Gillies, H., and Fraser, F. R · Brit M. J. 1:96 (Jan 19) 1935.
6. Homans, J · New England J Med 215·1099 (Dec 10) 1936
7. Homans, J , Drinker, C. K., and Field, M. E : Ann. Surg 100 812 (Oct) 1934
8. Kaposi, M. (Quoted by Dorffel, J.): Arch Dermat and Syph 26·608 (Oct) 1932.
9. Kondoleon [illegible]
10. Macey, H [illegible] 1940
11. Milroy, W [illegible]
12. Ochsner, A , Langaane, A. B , and Murray, S D : Surgery 8:383 (Aug) 1940
13. Sistrunk (Quoted by Ghormley, R K., and Overton, L. M.).

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Sudden Embolism and Thrombosis of Arteries of Extremities

Sudden occlusion of a major peripheral artery is a serious medical emergency. Unless prompt, effective treatment is instituted, gangrene of the effective limb or death of the patient may ensue Therefore, it is essential for every physician to be alert to the possibility of acute arterial occlusion in patients with symptoms referable to their extremities. In addition, he must be proficient in the diagnosis and skillful in the treatment of this syndrome. There can be no inadequate measures, diagnostic or therapeutic, if the best interests of patients with acute arterial occlusion are to be served.

Etiology: Acute arterial occlusion is most often the result of thrombosis or embolism, but may also be due to ligation or severance. Arterial thrombosis and embolism almost always occur as a result of disease of the arteries or of the heart. Sudden arterial occlusion occurs in approximately ten per cent of persons with arteriosclerosis obliterans and thromboangiitis obliterans (Buerger's disease). An atherosclerotic aorta and aortic and arterial aneurysms are at times the sites of thrombosis and, therefore, the source of emboli which dislodge to occlude a more distal artery. Less common as a cause of sudden arterial occlusion is an inflammatory process in the tissues surrounding an artery or an inflammation in the arterial wall occurring in the course of a severe infectious disease (mycotic arteritis).

Emboli may be released from the heart and result in acute arterial occlusion at some time in the course of several types of heart disorder; namely, auricular fibrillation, acute myocardial infarction, cardiac decompensation, cardiac aneurysm, or valvular heart disease. The type of valvular heart disease which is most frequently associated with arterial embolism is chronic rheumatic endocarditis with mitral stenosis and auricular fibrillation.

Sudden arterial occlusion is at times the result of surgical severance and ligation, traumatic severance owing to bullet or stab wounds, or a severe crushing wound.

Relat [illegible]
an arter [illegible]
related [illegible]
tion and cervical rib syndromes), and paradoxical embolism. The last-

TABLE 1
THE ETIOLOGIC CLASSIFICATION OF SUDDEN ARTERIAL OCCLUSION (ALLEN)

Embolism	Cardiac	Mitral and aortic valvulitis: Bacterial: Acute *Subacute* Mural thrombosis Failing heart from any cause
	Venous	Through patent foramen ovale
	Arterial	Mural thrombosis: Aneurysm Arteriosclerosis Trauma *Inflammation*
Thrombosis	Inflammatory	Thromboangiitis obliterans *Periarteritis nodosa* Mycotic arteritis (*severe infections*)
	Degenerative	Arteriosclerosis
	Traumatic	Surgical Cervical rib External trauma Gunshot and stab wounds
	Hematogenic	Thrombophilia Septicemia, peritonitis, pneumonia, etc
Ligation and severance		
Miscellaneous		

mentioned condition is the result of the passage of a venous embolism through a patent foramen ovale into the arterial circulation. There are instances of acute arterial occlusion in which no underlying disease is apparent. It has been proposed that in these instances the blood of the patient may clot more readily than normally. However, no laboratory tests prove this conclusively. Tables 1 and 2 summarize the etiology of acute arterial occlusion.

Pathophysiology: The immediate effect of sudden occlusion of a major peripheral artery is a marked decrease in the flow of blood to the affected extremity beyond the point of occlusion. This ischemia is noted most prominently in the distal portions of the extremity. In addition to organic occlusion, there is the factor of arterial spasm. There are no satisfactory objective means of measuring accurately the part played by arterial spasm in acute arterial occlusion. However, there is evidence to suggest rather strongly that spasm does play an important role in the symptomatology and prognosis of this syndrome: First, vascular surgeons have seen spasm of major arteries occur in the course of surgical procedures. Second, relief of symptoms and increased warmth of the affected extremity have been noted after anesthetization of lumbar sympathetic ganglia or after parenteral administration of papaverine. Since neither of these procedures

TABLE 2

THE CAUSES OF 100 CASES OF SUDDEN ARTERIAL OCCLUSION

	*Embolism**	*Thrombosis**
Heart disease	41	
Pelvic carcinoma	2	
Patent foramen ovale	1	
Arteriosclerosis	1	32**
Operation for cervical rib	1	0
Thromboangiitis obliterans		4
Following operations		8†
Ligation		1
Infection		5‡
Cervical rib		1
Indeterminate		3

* Not always absolute diagnosis

** Diabetes in five cases Twenty patients had symptoms previously of arteriosclerosis obliterans Disease of the coronary arteries, with or without decompensation or arrhythmia, present in twenty-one cases Arterial occlusion in some instances was probably due to embolism, but the diagnosis of thrombosis was made in all cases

† Carcinoma of cervix in one case, hysterectomy in two, division of posterior root of fifth cranial nerve in one, carcinoma of colon in one, amputation of cervix in one, herniotomy in one, resection of stomach for carcinoma in one

‡ Malaria, influenza, osteomyelitis, one case each, peritonitis in two cases

affects the actual occlusion, it is thought that improvement results from relief of spasm in patent collateral arteries.

Furthermore, digital compression of a femoral artery does not reproduce the clinical manifestations of sudden arterial occlusion, suggesting that some other factor (arterial spasm) is responsible for some of the manifestations of this syndrome. Finally, the severity of ischemia and the extent of subsequent necrosis of the affected limb seem at times out of proportion to the size of the artery occluded For example, surgical ligation of the popliteal artery usually is not followed by severe ischemia or gangrene while, on the other hand, acute occlusion of the popliteal (or lower part of the femoral) artery by thrombosis or embolism is frequently associated with marked ischemia and gangrene; it is believed that spasm of patent collateral arteries in acute arterial occlusion from thrombosis or embolism explains this discrepancy. It seems, therefore, that ischemia in sudden arterial occlusion is the result of organic arterial occlusion plus spasm of collateral arteries.

Fig. 1 is a diagrammatic sketch which demonstrates the relationship of organic arterial occlusion and arterial spasm to various degrees of ischemia.

In the artery distal to the site of occlusion and in spastic collateral arteries, there is a state of hypoxia and markedly decreased rate of blood flow. Both of these favor intimal damage and intra-arterial thrombosis. Unless treatment is promptly effective, the arterial circulation to the limb

is decreased not only be segmental occlusion from embolism or thrombosis, but also by thrombosis of the collateral arteries and of the occluded major artery distal to the point of occlusion. Thus, arterial spasm not only increases ischemia early in the course of acute arterial occlusion, but also causes severe ischemia owing to permanent occlusion of collateral arteries.

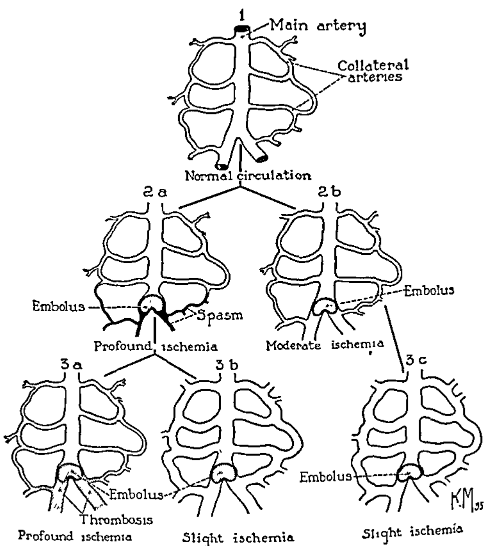


FIGURE 1 The probable course of events in arterial embolism: *1*, Normal arterial circulation at a specific point is maintained by the main and collateral arteries. *2a*, The embolus may be fixed at the point of lodgment by spasm, which [illegible] as both arte-
[illegible] ite ischemia
[illegible] erial spasm
[illegible] sults when
[illegible] prolonged
[illegible] n the blood
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[illegible] nproved by
[illegible] results.

Symptoms: The onset of symptoms after acute arterial occlusion may be sudden or insidious, with approximately fifty per cent of patients falling into each group. The symptoms which may be present with reference to the affected limb are pain, numbness, coldness, pallor, tingling, cramps, fulness, tenderness, burning, and itching. These are given in the approximate order of frequency with which they occur. The first three occur most frequently by far.

Pain in acute arterial occlusion may vary from mild to severe. It occurs in the ischemic portion of the affected limb and may be intermittent, or constant with intermittent exacerbations. It should be stressed, however, that pain is present as the initial symptom in only half the patients with acute arterial occlusion. If a physician, therefore, does not consider the possibility of acute arterial occlusion unless pain is initially present, he will be delayed in making a correct diagnosis in half of such cases.

Coldness and pallor may be considered as resulting directly from the sudden decrease in blood flow. Symptoms of pain, paresthesias (burning, tenderness, fulness, itching, tingling), numbness, and cramps are considered to represent the effect of ischemia upon the tissues of the affected extremity. For example, muscular spasm is the basis for cramps occurring in the ischemic extremity, and neuropathy owing to ischemia is the cause for numbness, paresthesias, and pain.

The duration of symptoms varies from hours to months (when chronic arterial insufficiency ensues) and depends largely upon the severity of ischemia. The latter represents the balance between the obstruction to blood flow in the occluded artery and the development of blood flow through patent collateral arteries. For example, if the occlusion is high in the femoral artery and if collateral blood flow is small, then there will be severe ischemia of the foot and lower part of the leg. On the other hand, if the occlusion is in the lower part of the femoral or in the popliteal artery and if collateral arterial flow is good, then a mild or moderate ischemia will result. As a rule, the smaller the artery involved and the greater the collateral arterial flow, the less will be the ischemia and, therefore, the shorter and milder will be the resultant symptoms There is no significant systemic reaction to acute arterial occlusion unless gangrene with infection and absorption of the products of necrosis occurs Prolonged severe pain, however, may result in deterioration of a patient's general condition owing to loss of sleep, inability to eat, and the emotional effect of the pain.

Physical Findings: The diagnosis of acute arterial occlusion requires not only alertness of the attending physician to the possibility of its presence, but also proper evaluation of the physical findings. The findings at examination of a patient with sudden peripheral arterial occlusion are easily recognized and explained. They are the direct result of sudden, marked decrease in peripheral arterial blood flow and interference with transmission of the arterial pulse wave. An affected limb is colder and paler than a normal limb. The veins are collapsed and the limb may appear somewhat shrunken. The deep reflexes, sensation to touch, and motor power of the affected limb are usually decreased or absent. Eleva-

tion of the affected limb produces marked pallor, and when the limb is then placed in a dependent position the veins fill slowly. In a normal limb they fill in ten to twenty seconds, but after sudden arterial occlusion the time which is required may be as long as ninety seconds.

Most important, the arterial pulsations are absent below the level of occlusion. This is the indispensable condition for the diagnosis of acute arterial occlusion. Skill in palpation of peripheral arteries is easily obtained with a little practice. It should be among the skills of all physicians so that they may approach the problem of patency or occlusion of peripheral arteries with confidence and certainty. A knowledge of previous peripheral arterial pulsations proves to be very helpful and speaks for routine recording of arterial pulsations in a medical examination.

Localization of the approximate level of arterial occlusion may be estimated by means of the physical findings. The presence or absence of arterial pulsations is the most important clue. For example, if pulsations are present in the femoral artery in the inguinal region but not in the popliteal artery, then the occlusion must be between the two sites somewhere in the thigh. Or, if the femoral pulsations are present in one extremity but not in the other, then the occlusion must be somewhere between the aortic bifurcation and the inguinal portion of the impalpable femoral artery. Other physical findings coincide with the level of arterial occlusion. In occlusion of the popliteal artery the coldness, pallor, and numbness will be in the region slightly above the ankle and distally therefrom. In occlusion of the femoral artery these findings will be noted in the region of the knee or lower part of the thigh, and in occlusion high in the iliac artery they will extend to the upper part of the thigh. Occlusion of the lower part of the abdominal aorta will result in absence of all pulsations in both legs and corresponding ischemia to the level of the hips and, at times, to the lumbosacral region.

Acute arterial occlusion may rarely be confused with acute ileofemoral thrombophlebitis. Occasionally, the latter condition is associated with marked arteriospasm, and the affected limb is cool and arterial pulses may be decreased or transiently absent. The patient may complain of pain in the affected limb. However, rather than shrunken, the limb may appear swollen if it is not actually edematous. Such a limb is ordinarily cyanotic rather than pale. The veins may be engorged instead of collapsed.

As a rule, sensation, reflexes, and motor power remain normal, and there is no pallor on elevation of the extremity. Rarely, the arterial spasm may be so severe as to reproduce the clinical picture of sudden arterial occlusion.

Important in the diagnosis is the fact that arterial pulsations soon return, and the leg assumes the appearance which is typical of iliofemoral thrombophlebitis.

Treatment: The importance of prompt, effective treatment in the prognosis of sudden peripheral arterial occlusion was referred to in the opening paragraph of this article. It is well to re-emphasize the qualifying words "prompt" and "effective," for these are the keystones of successful treatment. The element of time is crucial—the sooner correct treatment is instituted the better the prognosis. Time in this instance is measured in

hours, and twenty-four hours after the time of occlusion is considered late. The golden opportunity for successful treatment lies in the first six to twelve hours.

Not only are effective measures necessary, but it is equally essential that no harmful procedure be instituted. There are three "don'ts" in the treatment of acute arterial occlusion: Don't delay treatment; don't elevate the affected extremity, and don't traumatize the extremity (as with excessive heat or cold, rubbing, or strong ointments).

The treatment of sudden arterial occlusion may be medical or surgical, and the preponderance of either varies with different hospitals and localities. However, surgical therapy is limited for the most part to occlusions from emboli in which localization of the site of occlusion is reasonably accurate and in patients seen within a few hours (six to twelve) after onset of occlusion. Also, the patient's general condition must be good enough to permit the necessary anesthesia and surgical procedure Embolectomy performed when the occlusion involves an artery distal to the popliteal bifurcation is rarely, if ever, successful because of postoperative thrombosis of the involved artery. Embolectomy is rarely required in occlusion involving the upper extremities, because of the extensive collateral arterial circulation that is present. The experience of my colleagues and myself has been that only a small percentage of patients are suitable candidates for arterial embolectomy. We prefer to institute intensive medical therapy in most instances and we feel that our therapeutic results justify such an attitude.

Medical Treatment: A patient with acute arterial occlusion should be placed in a warm room with a temperature of 29 4° to 32 2° C. (85° to 90° F.). He should be in a bed the foot of which is slightly lower than the head in order to promote the effect of gravity on blood flow. We use the Sanders oscillating bed adjusted to maximal low-foot, minimal low-head position. This bed completes an oscillation every two minutes. The rocking motion of this bed has been shown to increase blood flow to the feet as determined by an increase in skin temperature.

It is well to support the limb with a pillow so as to prevent prolonged pressure on the heel which might result in gangrene. Similarly, the extremities should be protected from the weight of bed covers by a cradle to prevent excessive plantar flexion which might result in foot drop.

Attempts at vasodilatation should be instituted immediately. Of course, the warm environmental temperature tends to promote this. (*Caution:* Some elderly patients or patients with hyperthyroidism do not tolerate well an environmental temperature of 29.4° to 32 2° C. [85° to 90° F.].) Administration of 30 to 60 cc. (1 or 2 ounces) of whiskey every three or four hours is beneficial, the dose varying with the patient's size, age, and ability to tolerate the substance. Some persons who are elderly or who are not used to alcohol cannot tolerate it owing to nausea or excessive intoxication. When alcohol given orally produces nausea, an intravenous infusion of 1000 cc. of 5 per cent ethyl alcohol may be utilized to promote vasodilatation. This solution may be prepared by adding to a five per cent solution of glucose or to physiologic saline solution sufficient ethyl alcohol

to make a five per cent alcoholic solution. This acts as a sedative and may relieve pain. The rate of infusion should be regulated so as to produce vasodilatation and mild sedation without producing an undue degree of intoxication. Papaverine in doses of 32 to 100 mg. (½ to 1½ grains) may be given intravenously, or it may be given intra-arterially in the affected limb if an artery remains patent for injection. Intra-arterial injection is more effective than injection by the intravenous route. If successful in relieving arteriospasm, the dose may be repeated in two to four hours. (*Caution:* Morphine and papaverine should not be used concurrently, as they occasionally seem to cause marked suppression of respiration. Thus, if it is necessary to use morphine for control of pain, papaverine should not be administered concurrently.)

Anesthetization of the lumbar sympathetic ganglia with procaine or a similar substance is sometimes effective in relieving arterial spasm and in promoting increased collateral arterial blood flow in the lower extremity. This procedure is not, however, without risk of adverse effect, as rarely it has been known to be associated with very severe arterial spasm resulting in loss of a limb. (*Caution:* Lumbar sympathetic block should not be performed if the patient is receiving anticoagulant therapy, as fatal retroperitoneal hemorrhage at the site of needle puncture has occurred.)

Agents for blocking the autonomic nervous system, such as *tetraethylammonium chloride, hexamethonium, ansolysen,* and *priscoline* (2 benzyl-4, 5-amidazoline hydrochloride), have been used for producing vasodilatation in acute arterial occlusion. The use of such agents has shown a variety of results and to date does not represent a significant advance in treatment.

Anticoagulant Therapy: Anticoagulant drugs have a definite place in the treatment of acute arterial occlusion. Reference has already been made to the thrombosis which occurs in the artery distal to the site of occlusion and in the collateral arteries. Anticoagulant therapy is used, therefore, to combat this thrombosis and thereby to maintain a maximal patency of arterial circulation. My colleagues and I use combined therapy with heparin and dicumarol (bishydroxycoumarin). We administer 50 mg. of aqueous solution of heparin intravenously every four hours Also, at the onset of treatment we administer dicumarol by mouth, and when the activity of plasma prothrombin has been decreased to a therapeutic level, administration of heparin is discontinued and anticoagulant therapy is maintained by dicumarol alone.

Dicumarol is given orally in a dose of 300 mg. on the first day of therapy. Subsequent dosage of this drug is determined by its effect in decreasing the activity of plasma prothrombin. The latter should be maintained between ten and thirty per cent of normal, and measurement of this is achieved through determination of the plasma prothrombin time. The amount of dicumarol and the frequency of administration necessary to keep the activity of plasma prothrombin between ten and thirty per cent of normal vary widely from person to person. Therefore, it is necessary to obtain daily determinations of prothrombin time to avoid either insufficient or excessive administration of dicumarol. Because of the risk

of hemorrhage when this drug is given in excessive amounts and because insufficient dosage does not provide adequate anticoagulant effect, it should never be given unless laboratory facilities are available for performing reliable determinations of prothrombin time, and unless a physician skilled in its use is available to supervise.

When it is not feasible to use dicumarol, heparin may be used instead. However, there are difficulties in the administration of heparin over long periods. When it is given by continuous intravenous infusion or by intramuscular injection in a suitable menstruum, it is necessary to regulate the dosage by determination of the effect of heparin in prolonging the coagulation time of the blood. With continuous intravenous infusion of heparin, two to four determinations are required daily, and with intramuscular injection, one or two determinations daily. We attempt to maintain the coagulation time between fifteen and twenty-five minutes. Although it is usually possible to do this, the procedure is cumbersome. Without this means of regulation the attending physician cannot be certain whether the amount of heparin given is sufficient to provide an anticoagulant effect or is excessive, thereby increasing the risk of hemorrhage Heparin given every four hours in a dose of 50 mg. does not require laboratory control and has been shown to be effective as an anticoagulant. However, this procedure requires multiple injections, and after two or three days the discomfort of repeated injections is considered a nuisance by the patient.

Although anticoagulant therapy seems to be generally beneficial in the treatment of acute arterial occlusion, ecchymosis occurs at times in an ischemic extremity and gangrene sometimes follows the ecchymosis. Whether this is a direct result of anticoagulant therapy or whether it would have occurred anyway is not clear. However, this does not occur often enough to counterbalance the apparent benefit from anticoagulant therapy when this form of treatment is advisable.

So much has been said from time to time as to the merits of refrigeration in the treatment of acute arterial occlusion that a few remarks on the subject are pertinent. In my opinion and in the opinion of my colleagues, refrigeration has no place in the treatment of acute arterial occlusion when an attempt is to be made to save the affected extremity—it should never be used under this circumstance. However, we occasionally see patients who have very severe pain which is uncontrollable even with large doses of narcotic drugs or who are unfit for immediate surgical treatment owing to conditions such as cardiac decompensation, diabetes mellitus with acidosis, or marked systemic reaction due to gangrene with infection, and who obviously cannot hope for survival of the affected limb. In such instances refrigeration of the affected limb has been helpful in granting the necessary time to prepare the patient for amputation. Relief of pain and subsidence of systemic reaction to gangrene with infection ordinarily follow soon after institution of refrigeration. However, it should be emphasized that we use refrigeration only as a preliminary measure to amputation in cases as described above. When an attempt is to be made to save a limb, refrigeration, in our opinion, represents a severe form of trauma.

The basic medical treatment of acute peripheral arterial occlusion may be summarized as follows:

1. Place patient in bed with feet slightly lower than head.
2. Provide a room temperature of 29.4° to 32.2° C. (85° to 90° F.).
3. Protect affected limb from trauma.
4. Give 30 to 60 cc. (1 to 2 ounces) of whiskey by mouth.
5. Inject 32 to 100 mg. (½ to 1½ grains) of papaverine intra-arterially or intravenously.
6. Administer aqueous heparin intravenously in a dose of 50 mg. every four hours.
7. Administer 300 mg. of dicumarol by mouth on first day of treatment.
8. Obtain daily determinations of prothrombin time and regulate dicumarol dosage so as to maintain plasma prothrombin activity between ten and thirty per cent of normal. When this is achieved, discontinue administration of heparin. (Because heparin may increase the prothrombin time, blood on which the prothrombin time is to be determined should be drawn four hours after the last injection of heparin. By this means, inaccuracy of the test due to the effect of heparin will be avoided.)

Some optional medical measures in the treatment of acute peripheral arterial occlusion include:

1. Intravenous infusion of five per cent ethyl alcohol. Regulate rate of infusion by effect of alcohol on patient.
2. Anesthetization of lumbar sympathetic ganglia. This is contraindicated if patient is receiving anticoagulant drugs.
3. Administration of 8 to 16 mg. (⅛ to ¼ grain) of morphine for relief of pain. Concurrent use of morphine and papaverine is contraindicated owing to occasional instances of respiratory suppression resulting therefrom.

Surgical Treatment: The surgical treatment of sudden arterial occlusion is limited at present to those cases which are the result of embolism in the lower extremities. Embolectomy is ordinarily unnecessary in the upper extremities, as extensive gangrene rarely develops after embolism. Although by definition there is a distinct difference between thrombosis and embolism, in actual practice such a differentiation is difficult at times. There is no essential difference in the symptomatology of acute arterial occlusion whether it be caused by thrombosis or by embolism. In essence, embolism is presumed to have occurred when, in a patient with sudden arterial occlusion, there exists a possible source for embolism.

The accurate localization of the site of lodgment of the embolus is difficult in some instances. Although one may know approximately where an embolus is, the actual surgical discovery of the embolus may require extensive exploration of an artery and more than one incision. In such instances surgeons sometimes have found an embolus at a great distance from where it was originally considered to be. The one place where an embolus may be localized accurately is at the bifurcation of the abdominal aorta. An embolus at this site causes arterial insufficiency in both legs, and neither femoral artery is palpable. Not infrequently, however, after a few hours one or both femoral arteries may become pulsatile so that it

is not known whether the embolus became dislodged, moved distally, or both femoral arteries were impalpable because of severe spasm.

Thus it can be seen that there are difficulties involved in knowing whether or not acute arterial occlusion is due to thrombosis or embolism, and if the latter, just where the embolus is located. Nevertheless, there are a few cases in which it seems reasonably certain that arterial embolism has occurred, that it has occurred within a few hours of the time at which the patient is first seen, that localization of the site of lodgment seems clear, and that the general condition of the patient is good enough to permit surgical treatment. It is in these instances that embolectomy may be seriously considered, providing an experienced vascular surgeon is available to operate on the patient. We ordinarily attempt intensive medical treatment for three or four hours, and if no significant improvement occurs, proceed with embolectomy. Some physicians might feel that this wastes precious time. Nevertheless, our experience with medical treatment seems to justify this therapeutic approach. Certainly the majority of patients with acute arterial occlusion are not candidates for embolectomy, because they fail to fill one or more of the requirements of suitability for embolectomy. The delay in proper diagnosis after the onset of symptoms is one of the most frequent reasons that embolectomy is an unsuitable procedure, and if surgical treatment of acute arterial occlusion is to be given a fair trial, it behooves all physicians to increase their skill in the early diagnosis of this syndrome.

If embolectomy is to be performed, one should neutralize the effect of anticoagulant drugs if these have been administered. If embolectomy is being considered, in the course of medical therapy my colleagues and I administer heparin but not dicumarol, for heparin's anticoagulant effect lasts only about three to four hours after the intravenous administration of 50 mg. of the aqueous preparation. Also, its effect may be immediately neutralized by the intravenous administration of 50 mg. of protamine. If it is desired to neutralize the anticoagulant effect of dicumarol, one may administer intravenously 72 mg. of menadione sodium bisulfite (hykinone) or preferably 250 to 500 mg. of vitamin K_1 by mouth. The latter substance ordinarily results in a return of normal or near-normal activity of plasma prothrombin within six to twelve hours, whereas menadione sodium bisulfite may require eighteen to thirty-six hours to do the same. After embolectomy we administer combined anticoagulant therapy with heparin and dicumarol in the manner described earlier in this paper.

The conditions under which surgical treatment of acute peripheral arterial occlusion is justifiable are

1. When occlusion is due to embolism.
2. When location of embolic occlusion is apparent.
3. When general condition of patient is good enough to permit operation on affected limb.
4. When patient may be operated on within a few hours after occurrence of embolism.
5. When an experienced vascular surgeon is available to operate on patient.

The treatment of sudden peripheral arterial occlusion when embolectomy is contemplated is as follows:

1. Administer basic medical treatment as summarized earlier in the discussion, but give patient no dicumarol by mouth.
2. If after three or four hours of medical therapy there is no significant improvement in affected limb, proceed with embolectomy. If four hours have not elapsed since last intravenous administration of aqueous heparin, administer intravenously 50 mg. of protamine to counteract anticoagulant effect of heparin.
3. In event that improvement of affected limb occurs and embolectomy is not performed, continue medical treatment and begin administration of dicumarol.

RECURRENT ACUTE ARTERIAL OCCLUSION

At times one is faced with the problem of recurrent acute arterial occlusion owing to severe heart disease. The latter, in these instances, is most often due to rheumatic endocarditis with mitral stenosis and auricular fibrillation. This is, indeed, a very difficult problem aside from the aspect of treatment of each incident of acute arterial occlusion. If, after careful evaluation of the patient's cardiac status, it is deemed feasible to attempt conversion of the auricular fibrillation to a sinus rhythm, this may be attempted with the use of quinidine. My colleagues and I feel that it is advisable to have such patients under the anticoagulant effect of dicumarol prior to the onset of quinidine administration, for the purpose of avoiding embolism at the time of conversion. If conversion to sinus rhythm occurs, when may anticoagulant therapy be discontinued? There is no accurate answer to this question, but we presume it is safe to discontinue the administration of anticoagulant drugs two or three weeks after conversion of the cardiac rhythm.

If conversion is unsuccessful and if arterial embolism has been recurrent, anticoagulant therapy with dicumarol may be used over a period of months or years in an attempt to prevent additional embolic phenomena. The difficulties of such a procedure are many, including the problem of availability of proper control (without which dicumarol therapy should never be instituted), cost and inconvenience to the patient, risk of hemorrhage, and the question as to when treatment may be safely terminated. The answer to the last factor is unknown, although one might consider cessation of anticoagulant therapy after six to twelve months of freedom from thromboembolic phenomena.

EFFICACY OF MEDICAL TREATMENT

Recent statistical studies have not been made by our group, but in the past, survival of the involved extremity has occurred in ninety-one per cent of instances of embolism when treatment has been instituted within twenty-four hours of the onset of symptoms. When treatment was begun twenty-four or more hours after the onset of symptoms, the rate of survival of the extremity fell to twenty-five per cent. In acute arterial occlusion due to thrombosis, survival was noted in eighty-one per cent of

cases when treatment was begun within twenty-four hours but in only fifty per cent when begun after twenty-four hours' delay.

If embolic phenomena recur after cessation of anticoagulant therapy, then this form of treatment should be reinstituted for as long a time as possible.

NELSON W. BARKER, M.D.

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Thrombophlebitis

In this discussion the term "thrombophlebitis" is used to include a number of different diseases of the veins which produce the common pathologic manifestations of thrombosis and inflammatory reaction in the wall of the vein. It is generally agreed that thrombophlebitis may be initiated by disease or injury of the endothelium of the vein, the thrombosis in this case being secondary. It is also agreed that venous thrombosis may develop without evidence of pre-existing disease in the endothelium or wall of the vein. However, clinical, experimental, and pathologic evidence indicates that a thrombus as such does not remain in the lumen of the vein for more than a few hours before a secondary inflammatory reaction develops in the wall of the vein as a result of the presence of the thrombus. Conditions which have been designated in the literature as venous thrombosis, phlebothrombosis, venous thromboembolic disease, and thrombophlebitis are all included in this chapter under the general category, thrombophlebitis. Although it is well recognized that the degree of inflammatory reaction in the wall of the vein which follows venous thrombosis varies greatly, it is the opinion of the author that attempts to separate cases into two groups designated respectively as phlebothrombosis and thrombophlebitis leads only to confusion. Authors do not agree on the basis for this distinction and no useful purpose is served by it either from the standpoint of diagnosis or treatment.

Etiological Factors: Although thrombophlebitis may be strictly classified as primary or secondary, or as due to local injury or disease and not due to local injury or disease, such a classification is not of much clinical value. A working classification of thrombophlebitis on the basis of what is known of the etiologic agents or factors which produce the lesion and the underlying diseases of which thrombophlebitis may be a complication has proved useful and is as follows:

A. Local thrombophlebitis; thrombophlebitis due to direct trauma or disease of the vein such as:
   1. Chemical injury.
   2. Local mechanical trauma.
   3. Local inflammatory reaction in the surrounding tissues.
   4. Suppurative disease associated with local abscesses and other suppurative processes which invade and involve the vein itself, called "suppurative thrombophlebitis."
   5. Varicose veins

6 Other local diseases of veins, such as neoplastic invasion or compression by tumors, aneurysms, or scar tissues.
7. Ischemia resulting from occlusive arterial disease and arterial insufficiency.

B. Primary thrombophlebitis; no known previous injury or disease of the vein
1. Associated with thromboangiitis obliterans.
2. Recurrent idiopathic thrombophlebitis (thrombophlebitis migrans).
3. Nonrecurrent idiopathic thrombophlebitis.

C. Secondary or complicating thrombophlebitis; no known injury or disease of the vein
1. Developing postpartum.
2 Developing after operation.
3. Complicating severe injury and developing at a site remote from the site of the injury.
4. Complicating infectious diseases of any type, bacterial or viral.
5 Complicating blood dyscrasias, particularly polycythemia vera and leukemia.
6 Complicating pregnancy.
7. Complicating heart disease, particularly congestive heart failure and acute myocardial infarction.
8. Complicating carcinoma originating at any site and particularly carcinoma of the pancreas.
9 Complicating other noninfectious diseases, such as gout, nephrolithiasis, cholelithiasis, and sarcoma.
10. Following the use of certain drugs, such as the steroid hormones, barbiturates, and digitalis.

It is generally agreed that thrombophlebitis develops as a result of one or more of the following three factors: Disease or injury of the endothelium of the vein, relative stasis or other disturbance of venous blood flow, and increased coagulability of the blood. It is probable that in the local and primary types of thrombophlebitis the dominant factor is a disease or injury of the endothelium of the vein, although the extent of the thrombus may be determined by either of the other two factors or both. In thrombophlebitis in varicose veins, disturbances in blood flow may be equally as important as the disease of the wall of the vein itself. In the various types of secondary or complicating thrombophlebitis, however, there is little if any evidence to incriminate a lesion of the endothelium of the vein as a starting point for the development of the thrombus. In these conditions it is probable that the thrombus is primary and the reaction in the wall of the vein is secondary.

In most instances when secondary thrombophlebitis develops, there is reason to believe that stasis or other disturbances of venous blood flow may be present. For example, in many of these cases, a period of rest in bed has preceded the development of thrombophlebitis, and it is known that rest in bed results in decrease in the venous blood flow. Also there is much indirect evidence that increased coagulability of the blood is a potent

factor in the secondary types of thrombophlebitis. However, actual tests of various coagulation factors have been somewhat inconsistent and in general disappointing as an indication of this disturbance. A simple coagulation test which would indicate a tendency to thrombosis or lack of it would be highly desirable but so far no reliable test has been found. In some patients with secondary thrombophlebitis there is shortening of the clotting time of whole blood in glass tubes, in others there may be thrombocytosis or morphologic abnormality of the platelets. When the coagulation time of whole blood is measured in silicon tubes at 37° C (98.6° F.), it is usually, but not always, shorter for patients who have thrombosis than for those who do not have it. For patients with thrombosis tests of tolerance to heparin *in vivo* and tests of blood to which fixed amounts of heparin were added *in vitro* have frequently but not always shown shorter coagulation times than are noted when the same tests are done on normal individuals. Tests of the prothrombin time have given variable results, both when done by the one-stage and two-stage method. Determinations of the fibrinogen content of the blood also have been variable. Failure to find any consistent abnormality in the coagulation of blood of patients in whom secondary thrombophlebitis has developed recently has been ascribed to the possibility that the disturbance in coagulation may have been transient or that the formation of the thrombus itself may have restored the disturbed coagulation to normal as a result of using up the abnormal excess of a coagulation factor or factors.

Except in suppurative thrombophlebitis, a rare entity in recent years, there is no evidence to indicate that any of the other types are the result of either bacterial or viral disease of the vein itself. Even in those cases of thrombophlebitis which are complications of specific infectious or viral diseases, no evidence of direct involvement or injury of the endothelium or wall of the vein by bacteria or viruses has been produced.

Pathologic Aspects: From the pathologic standpoint there are three types of venous thrombi, red or coagulation thrombi, white or agglutination thrombi, and mixed thrombi. Red thrombi such as those usually found in involved superficial veins are more or less homogeneous and resemble postmortem clots. The thrombocytes and leukocytes are scattered evenly within a gelatinous mass of erythrocytes and fibrin. White thrombi consist of fibrin and layers of platelets and leukocytes with relatively few erythrocytes. The commonest type of thrombus is the mixed type which consists of a white thrombus as the head, a lamellated red and white thrombus as the body, and a red or lamellated red and white thrombus as the tail. The tail extends in a proximal direction from the head. The mixed thrombus is the one commonly found in large and deep veins in the secondary types of thrombophlebitis. As a result of slow flow and eddies in the blood stream plus changes in platelet-plasma stability, the platelets tend to accumulate in the slower moving periphery of the stream and stick to the endothelium. They may stick at the site of a pre-existing lesion of the endothelium, or no such lesion may be found at the site of the inception of this type of thrombus. Platelets then disintegrate, leukocytes are attracted, and a small amount of fibrin is precipitated. These events are

followed by the deposits of more platelets, fibrin, and leukocytes in layers Thus, the white head of the mixed thrombus is formed which may or may not occlude the lumen of the vein. The body and the tail develop in a proximal direction, that is, toward the heart. It is probable that the increased coagulability of the blood, even though slight, is the chief factor responsible for the development of the body and tail of the thrombus. The whole process usually develops rapidly because sections through various portions of a red or lamellated red and white thrombus are similar in appearance; however, the consistency and cohesion of the thrombus may vary greatly in different cases. In some instances it may be firm and fill the vein. In others it may be more pliable and not completely fill the lumen of the vein. Unless a large portion or all of the thrombus detaches soon after its formation, it becomes attached to the wall of the vein and sets up the secondary inflammatory reaction in the wall. Within a few days organization takes place at the margins of the thrombus. In small veins the organization may be complete and gradually convert the involved segment of the vein into a solid contracted cord. In large veins, however, the process of involution is one of marginal organization and central liquefaction. Thus, in almost all instances of thrombosis of large veins the process heals with partial restoration of the lumen of the vein. Almost always there is some remaining fibrosis in the periphery, and the vein becomes thicker walled and somewhat contracted in diameter. When veins containing valves are involved by the process, the valves are almost always stuck in the fibrosed periphery of the organized thrombus, and thus rendered incompetent permanently.

The degree of periphlebitic reaction during the acute stage is variable in different patients. Considerable periphlebitic inflammatory reaction is usually found in the local and primary types of thrombophlebitis, particularly when these involve superficial veins. The periphlebitic reaction is apt to be considerably less in the secondary types of thrombophlebitis. In the now rare suppurative type of thrombophlebitis, the thrombus contains many bacteria, and thus is a focus for bacteremia which is an almost invariable accompaniment of such a lesion.

Clinical Manifestations: Thrombophlebitis is an acute disease which tends, as far as the individual lesions are concerned, to run its course and involute in a few weeks. If a large vein is affected, a residuum of chronic venous insufficiency of the limb may remain. When small veins are affected, there may be no residual manifestations. In some instances the lesions of thrombophlebitis may extend in a series of episodes or the lesions may recur in veins of other parts of the body.

The clinical manifestations of thrombophlebitis are the result of periphlebitic reaction and obstruction to venous blood flow with distal congestion. The occurrence of constitutional reactions, such as fever, tachycardia, and malaise, is variable among different patients who appear to have the same degree of local involvement. Severe constitutional reactions are rare. Chills do not occur except in those rare cases of suppurative thrombophlebitis and the temperature, rarely if ever, rises to 38.9° C. (102° F.). Slight to moderate tachycardia may occur. Many patients who have rather exten-

sive thrombophlebitis in a limb have no constitutional reaction. The symptoms and signs of acute thrombophlebitis are considered herein on the basis of the location of the lesion rather than on the basis of the etiologic factors or of the primary condition which is usually obvious.

Superficial Thrombophlebitis of the Lower Extremity: These lesions occur in small superficial veins, in segments of the great or small saphenous veins, the medium basilic, the medium cephalic, or superficial varices. Most of the lesions in these veins are either of local or primary origin but they may be seen as complications of infectious diseases, blood dyscrasias, or



FIGURE 1 Primary thrombophlebitis involving superficial veins of inner side of foot

visceral carcinoma. The lesions may be multiple and appear as red, moderately painful, tender raised regions in the skin (Fig 1). In small veins the lesions may be oval or round but they are usually linear and can be felt as firm, cordlike segments in the course of a visible, superficial vein Constitutional symptoms are rare, and the inflammatory reaction undergoes involution in from seven to eighteen days, but the thrombosed portion of the vein may be felt for a much longer period. At times, lesions in small veins may extend segment by segment to larger veins.

Deep Thrombophlebitis of the Veins of the Calf: These lesions are mostly secondary types of thrombophlebitis and occur particularly in patients who have been at rest in bed. The lesions may occur in small muscular veins of the calf muscles and in the posterior tibial veins, but the commonest site of involvement is in the sural veins, two large muscular veins which lie within the soleus muscle. The signs and symptoms of thrombophlebitis of these veins are pain in the calf muscles and tenderness, particularly on bilateral pressure. There may or may not be slight enlargement and tenseness of the calf muscles and prominence of the superficial veins in the lower part of the leg Edema rarely occurs and constitutional symptoms are minimal. Any patient who complains for the first

time of pain and tenderness of *one calf during* the second postoperative or postpartum week should be *suspected* of having thrombophlebitis of the sural veins. Homans' *sign, that is,* pain in the *calf on forcible* dorsiflexion of the foot, may be present but it is *not a reliable* diagnostic sign since it may be present in other lesions such as peripheral neuropathy, and it may be absent in proved instances of acute thrombophlebitis of the sural veins.



FIGURE 2 Acute iliofemoral thrombophlebitis complicating chronic ulcerative colitis, infrared *photograph;* superficial veins are distended in spite of elevation of leg

Thrombophlebitis of the Popliteal and Lower Segment of the Femoral Veins: These lesions also are mostly secondary in origin and usually occur in association with, or as an extension of, involvement of the deep veins of the calf. Pain and tenderness are felt in the popliteal space and often along the lower portion of Hunter's canal in the thigh as well as pain in the calf. There may be mild constitutional symptoms. Some transient swelling and congestion usually appear in the lower part of the leg and foot.

Iliofemoral Thrombophlebitis: This condition, like deep thrombophlebitis in the calf, is usually a secondary type of thrombophlebitis, although it may occur as a primary idiopathic condition. It also may develop as an extension of thrombophlebitis in the lower segment of the femoral vein. Mild constitutional symptoms are usually present. As in other types of thrombophlebitis the *onset* is usually acute. There is commonly pain in the thigh, the *groin,* and also in the calf and sometimes in the gluteal region and lower part of the abdomen on the affected side. In some individuals the pain *may* be minimal.

The diagnostic triad of physical signs indicating iliofemoral thrombophlebitis is enlargement of the leg and thigh, evidence of congestion as shown by slight cyanosis or prominence of the superficial veins of the thigh and leg (Fig. 2), and tenderness in Scarpa's triangle. The skin temperature of the leg and foot is usually the same as that of the companion extremity but may be slightly warmer. In rare instances the leg and foot are cold due to a transient secondary arteriospasm. Diffuse redness of the leg and foot does not occur. Occasionally a severe type of thrombophlebitis develops acutely in the lower extremity and involves not only the iliofemoral vein but also the saphenous veins with extensive thrombotic obstruction. This condition has been described in the literature under the term "phlegmasia cerulea dolens." It is characterized by the rather sudden development of massive swelling, cyanosis, and congestion of the leg and thigh. In some patients shock develops, and this is attributed to the trapping of a large amount of blood and fluid in the involved limb. Gangrene of the toes or portions of the foot has occurred rarely in cases of phlegmasia cerulea dolens and is attributed to almost complete stasis of venous blood flow in the distal portion of the extremity. Phlegmasia cerulea dolens is a rare condition. When it occurs, it is usually associated with advanced and metastatic carcinoma.

Axillary-Subclavian Thrombophlebitis: Acute axillary-subclavian thrombophlebitis produces a similar clinical picture in the arm to that produced in the leg by iliofemoral thrombophlebitis. The arm and forearm are enlarged and congested with some cyanosis and prominence of superficial veins. The thrombosed axillary vein can be felt easily in most cases as a tender cord. Axillary-subclavian thrombophlebitis may occur rarely as a secondary type of thrombophlebitis but in most instances it occurs as the result of effort or strain of the arm. The majority of the cases have occurred in the dominant arm of athletes such as baseball players, football players, gymnasts, boxers, and wrestlers. Occasionally, however, the effort or strain which seems to be responsible for the development of thrombophlebitis in this location seems minimal.

Thrombophlebitis of the Inferior Vena Cava: Acute thrombophlebitis of the inferior vena cava may develop as an extension of iliofemoral thrombophlebitis. It produces swelling of both legs, thighs, and hips, and sometimes of the lower part of the abdomen and back. Superficial veins in both the legs and the lower part of the abdomen are prominent and distended. Pain and tenderness in the legs and thighs are variable and may be minimal; systemic reactions are inconstant. Direct venous pressures in superficial veins are increased to 300 to 500 mm. of water in both legs but are normal in both arms. As time goes on after the acute stage has subsided, extensive varices may develop in the superficial veins of both legs and the lower part of the abdomen (Fig. 3).

Thrombophlebitis of the Superior Vena Cava: This condition may occur rarely as a primary disorder, but is most frequently secondary to obstruction of the superior vena cava by tumors, aneurysms, or extracaval inflammatory processes. Swelling and congestion occur on both arms and the face and neck. Superficial views on the chest wall and arms are prominent,

and the external jugular veins are distended. Venous pressures are increased in both arms but normal in both legs. Systemic reactions are usually absent.

Diagnosis: The diagnosis of thrombophlebitis is not difficult if the signs and symptoms are kept in mind, if the causative factors are remembered, and if attention is paid to the various conditions which may favor the



FIGURE 3 Dilated, tortuous, superficial abdominal and thoracic veins in old case of thrombophlebitis of inferior vena cava, infrared photograph

development of thrombophlebitis as a secondary complication. Thrombophlebitis of superficial veins does not produce large circular nodules. These are more likely caused by erythema nodosum, erythema induratum, or the condition known as "nodular vasculitis." In doubtful cases biopsy of the lesion can be done. Acute thrombophlebitis of superficial veins does not cause large indurated red plaques in and under the skin. Such lesions are usually the result of nonsuppurative panniculitis or of chronic or subacute

indurated cellulitis, a complication of edema and chronic venous insufficiency of the limb. Thrombophlebitis does not produce a swollen, red, hot limb associated with chills and fever. Such findings are usually indicative of diffuse lymphangitis. Also, thrombophlebitis does not produce a cold, pale, somewhat shrunken limb with collapsed veins; it does not impair pulsations in the arteries except in rare instances and does not cause muscular weakness or impairment or absence of sensations. This combination of clinical manifestations is almost always the result of acute arterial occlusion.

The most difficult type of thrombophlebitis for positive diagnosis is thrombophlebitis of the deep veins of the calf. In many instances the diagnosis of this condition can only be presumptive, but diffuse tenderness in the calf muscles elicited on bilateral pressure and developing acutely during the second or third week after an operation, childbirth, or severe injury, or during the course of an infectious disease, or the period when a patient is in bed because of serious heart disease should be considered presumptive evidence of deep-calf thrombophlebitis if no other obvious cause can be found. Thrombophlebitis in the sural and posterior tibial veins may be demonstrated by venography but venography is not recommended as a routine procedure. The technic is not simple and considerable experience is necessary for the proper interpretation of the roentgenograms. The best clinical judgment is usually to treat the patient for deep thrombophlebitis of the calf if a presumptive diagnosis can be made and not to resort to venography to establish the diagnosis definitely.

Recurrent superficial and deep thrombophlebitis may be the first clinical manifestation of an obscure visceral carcinoma, particularly carcinoma of the body or tail of the pancreas. Such a primary cause should be suspected if the history is short, the patient more than fifty years of age, and the sedimentation rate of the erythrocytes rapid.

COMPLICATIONS AND SEQUELAE

Pulmonary Embolism: Pulmonary embolism is rare in the local types of thrombophlebitis and in thromboangiitis obliterans. It occurs at some time during the course of recurrent idiopathic thrombophlebitis in about twelve per cent of cases. The majority of instances of pulmonary embolism occur in association with the secondary types of thrombophlebitis or in the same conditions in which secondary thrombophlebitis develops. Actually both secondary thrombophlebitis and pulmonary embolism can be considered as manifestations of the same underlying process, that is, venous thrombosis.

Fatal pulmonary embolism most commonly occurs suddenly and without clinical evidence of antecedent thrombophlebitis. When nonfatal pulmonary embolism or pulmonary infarction develops in association with thrombophlebitis, the clinical manifestations of the pulmonary embolism usually antedate rather than follow the clinical manifestations of the thrombophlebitis. This is owing to the fact that only a fresh thrombus a few minutes or a few hours old detaches to become an embolus. If the thrombus remains in the vein for a longer period, it adheres to the wall

and the signs and symptoms of thrombophlebitis develop. *When pulmonary embolism occurs after the signs and symptoms of acute thrombophlebitis have become evident, it is almost always the result of sudden proximal extension of the thrombus or the development of another thrombus in a different vein.* Thus, when thrombophlebitis has been diagnosed, pulmonary embolism may be prevented if extension of thrombosis or development of new thrombosis in other veins can be prevented.

Small pulmonary emboli which produce pulmonary infarctions cause sudden onset of pleural pain, often transient development of a friction rub, suppression of breath sounds, and a few rales in the involved area, and may produce cough with hemoptysis of bright red blood. Transient fever and tachycardia occur frequently. There is no characteristic roentgenographic finding in pulmonary embolism. However, some roentgenographic findings are at least suggestive. The diaphragm may be elevated on the affected side; the hilar markings may be prominent; occasionally there is a rounded shadow in the periphery, and there is frequently local haziness which has been characterized as a pleural reaction. The roentgenographic findings and the constitutional reaction are minimal as compared with those seen in pneumonia. Larger but nonfatal pulmonary emboli may produce pain in the midline of the thorax, marked tachycardia, fall in blood pressure, and the general appearance of shock. The electrocardiogram is *usually normal* in pulmonary embolism but in some instances, particularly those in which a shocklike picture is produced, the electrocardiographic findings may be indicative of acute cor pulmonale. Thus in some cases, the electrocardiogram may be of value in making the differential diagnosis between pulmonary embolism and acute myocardial infarction.

Chronic Venous Insufficiency of the Limb: Chronic venous insufficiency of the limb is a serious complication of iliofemoral thrombophlebitis. The basis for chronic venous insufficiency is usually incompetency of the valves of the iliofemoral vein because of their adhesion to the wall of the vein. Less commonly the iliofemoral vein may be partially or completely obstructed by a fibrotic organized thrombus. The manifestations of chronic venous insufficiency of the limb are persistent orthostatic edema, the development of secondary varices, and finally the development in the lower part of the leg and around the ankle of chronic indurated cellulitis, stasis eczema or stasis ulceration, or any combination of these rather disabling complications. In the presence of chronic venous insufficiency there may be localized pruritus. Persistent scratching or irritating antipruritic topical applications may precipitate eczema. Blunt trauma sometimes of only mild degree may precipitate the development of stasis ulcers.

Postphlebitic Neurosis: This syndrome which occurs almost exclusively in women is characterized by persistent, diffuse, or localized pain in the extremity, paresthesias and muscular weakness. The symptoms are out of all proportion to any demonstrable disturbance of circulation. Objective signs of chronic venous insufficiency are usually absent. In almost all cases of postphlebitic neurosis the patient has been kept in bed because of acute thrombophlebitis for an unjustifiably prolonged period, usually months, and often only slow ambulation with prolonged use of crutches

has followed. Almost all of the patients have been strongly impressed with the idea that they have "blood clots" in their legs and that these blood clots may detach at any time and cause serious disability or death. The syndrome of reflex sympathetic dystrophy of the limb which occasionally occurs as a complication of iliofemoral thrombophlebitis is usually associated with postphlebitic neurosis.

TREATMENT

General Measures: For all types of acute thrombophlebitis, an early diagnosis and the early institution of the indicated treatment are important. Acute thrombophlebitis of superficial veins of chemical, local inflammatory, or varicose origin often requires little in the way of specific treatment. The local application of hot, wet packs may ease pain and promote involution of the lesion. Phenylbutazone (butazolidin) in doses of 200 mg. four times a day for three or four days has been said to produce rapid involution of the periphlebitic reaction. If varicose thrombophlebitis is extensive, it may be advisable to keep the patient in bed for one or two weeks until the periphlebitis has subsided. Since these types of superficial thrombophlebitis are rarely complicated by pulmonary embolism, anticoagulant therapy is not necessary or indicated unless the lesions spread proximally or continue to recur and involve larger veins. The presence of acute or subacute thrombophlebitis in superficial varices is not a contraindication to surgical removal of these veins Surgical removal or proximal ligation of involved varices may be advisable if thrombophlebitis is progressive and disabling.

For the secondary types of thrombophlebitis involving the deep veins of the calf and lower part of the femoral veins, it is advisable to keep the patient in bed for approximately seven to ten days at the end of which time tenderness and other signs and symptoms usually will have disappeared. *Hot, wet packs should be applied to the leg from the foot to the* midthigh, and slight elevation of the leg is advisable. When the patient becomes ambulatory, a light-weight elastic bandage or elastic stocking should be worn for four to twelve weeks. Anticoagulant therapy should be started as soon as the diagnosis is made and continued until the patient has been ambulatory for at least one week.

For acute iliofemoral thrombophlebitis, the patient should be kept in bed, and the leg elevated to an angle of thirty degrees. Hot, wet packs should be applied from toes to groin. The patient should be kept in bed until all swelling is gone below the knee and until tenderness has disappeared from Scarpa's triangle. As a general rule, rest in bed should be maintained for at least ten days but practically never for longer than twenty days When the patient is allowed out of bed, an adequate supporting bandage should be applied from toes to knee. An adequate supporting bandage is one which prevents the development of orthostatic edema. Two 10 cm (4 inches) elastic mesh bandages may be sufficient. *If they are not, a solid rubber bandage applied over a white cotton stocking* should be used. An elastic stocking may be used if it prevents orthostatic edema. As a general rule, the elastic support should be worn all the

time that the patient is up and around for at least three months and then its use may be gradually discontinued if orthostatic edema fails to develop when it is not worn. For patients who have iliofemoral thrombophlebitis the diagnosis should be made early and anticoagulant therapy be started as soon as the diagnosis is made. Anticoagulant therapy should be continued until the patient has been ambulatory for at least a week.

For axillary-subclavian thrombophlebitis the arm should be elevated and hot, wet packs applied as for iliofemoral thrombophlebitis. Anticoagulants should be given for a period of approximately two to three weeks. After the acute stage has subsided an elastic mesh bandage may be applied from the hand to well up into the arm. Persistent edema, however, is seldom a serious problem in the upper extremity.

Anticoagulant Therapy: The chief purpose of anticoagulant therapy is to prevent extension of thrombosis or new thrombosis in other veins and, therefore, to prevent pulmonary embolism. However, recent experimental evidence indicates that anticoagulant therapy, if started soon after a thrombus has developed, also may help produce more rapid involution and lysis of the existing thrombus. When anticoagulant therapy is started early in iliofemoral thrombophlebitis, it appears to shorten the course of the acute phase of the disease in many instances. Currently, the most effective type of anticoagulant therapy for acute thrombophlebitis is the intravenous administration of heparin, 50 mg. every four hours, and the simultaneous oral administration of one of the coumarin or indandione compounds. Administration of heparin is discontinued as soon as therapeutic hypoprothrombinemia is produced by the coumarin or indandione compound, and anticoagulant therapy is maintained for the rest of the required period with the orally administered drugs. Coumarin or indandione compounds should not be used unless facilities are available for accurate and comparable tests of the one-stage prothrombin time. After the initial or priming dose of the coumarin or indandione compound, the daily maintenance dose should be individualized and varied as necessary on the basis of the prothrombin time tests and the prothrombin time should be kept within the therapeutic range.

The generally accepted contraindications and cautions regarding conditions which may favor excessive reaction or local bleeding should be carefully considered. If serious bleeding should develop in spite of precautions, vitamin K_1 should be given to correct the prothrombin deficiency as rapidly as possible. If necessary, blood transfusions should be given to replace loss of blood.

Ligation of Veins: In the treatment of thrombophlebitis the purpose of ligation of a vein is to prevent pulmonary embolism. If adequate anticoagulant therapy can be given, ligation should be unnecessary and used only in those rare cases in which anticoagulant therapy has failed to prevent pulmonary embolism. In general, ligation of the common femoral vein for thrombophlebitis of the deep veins of the calf or lower part of the femoral vein has not been statistically effective in the prevention of pulmonary embolism. Actually the only ligation procedure which is rational for prevention of pulmonary embolism from thrombosis in the veins of the

lower extremities is ligation of the inferior vena cava. This is an operation of considerable magnitude and not without risk to life It also may result in considerable increase in chronic venous insufficiency in the limb affected by thrombophlebitis. The early enthusiasm for venous ligation as a means of preventing pulmonary embolism has largely disappeared, and this procedure has been replaced for the most part by anticoagulant therapy.

Local Anesthetization of Regional Sympathetic Ganglia: This procedure which was formerly advocated for patients who had iliofemoral thrombophlebitis has largely been abandoned. Even in cases in which there is secondary arterial spasm, the effect of transient sympathetic block has not appeared to shorten the course of the disease or ameliorate the symptoms other than to produce some temporary relief of pain, an effect which can be accomplished much more easily by simple analgesic drugs.

Trypsin: In recent years, parenteral administration of trypsin has been advocated first as a fibrinolytic agent and second as an agent which would cause rapid involution of the periphlebitic reaction. The intravenous administration of trypsin in dilute solution has not been shown to have any definite value in producing fibrinolysis in thrombi or in increasing the tempo of normal thrombolysis, unless the dose is increased to dangerously high levels. The administration of trypsin by intramuscular or deep subcutaneous injection has been said to produce more rapid involution of the periphlebitic reaction, but this effect is questionable and currently it seems doubtful that trypsin or similar enzymes are of enough value in the treatment of acute thrombophlebitis to justify their use.

Therapeutic Considerations in Special Types of Thrombophlebitis: In the rare types of suppurative thrombophlebitis, antibiotic therapy should be used. The antibiotic should be selected for its specific effect on the type of organism which is found in cultures of material from the lesion or of the circulating blood. For other types of thrombophlebitis, antibiotics are of no value. When thrombophlebitis complicates an infectious disease of bacterial origin, the appropriate antibiotic should be used in the treatment of the infectious disease but it will not affect the thrombophlebitis itself

The superficial thrombophlebitis, which occurs in association with thromboangiitis obliterans, is rarely in itself a serious problem. If the patient maintains complete abstinence from tobacco, recurrences of the thrombophlebitis are rare.

For some patients who have recurrent idiopathic thrombophlebitis, abstinence from tobacco may stop recurrence of the lesion. In a few others the daily use of one of the antihistaminic drugs has seemed to prevent recurrences. However, in a number of cases both of these measures have failed, and the only procedure which has resulted in the prevention of recurrence of the thrombosis and even of pulmonary embolism has been long-term anticoagulant therapy. There are no rules as to how long the anticoagulant therapy should be maintained in cases of recurrent idiopathic thrombophlebitis. If adequate facilities for careful control of dosage are available and the patient's tolerance remains reasonably constant, anticoagulant therapy should be continued for at least one year and in some patients for a considerably longer period.

For patients who have recurrent thrombophlebitis as a complication of visceral carcinoma, long-term anticoagulant therapy may be tried, but in most cases it becomes increasingly ineffective as time goes on and usually use of anticoagulants is finally abandoned because they do not prevent thrombophlebitis even when the prothrombin content of blood is kept within the therapeutic range.

When the first manifestation of venous thromboembolic disease is a pulmonary embolus, anticoagulant therapy should be instituted immediately and continued at least until the patient has been ambulatory for one week. Patients with small pulmonary infarcts should be kept in bed for approximately one week or until symptoms have disappeared. For the more severe types of pulmonary embolism with shock or shocklike manifestation, additional immediate treatment should include oxygen and one intravenous administration of 32 to 65 mg. (½ to 1 grain) of papaverine hydrochloride and 0.65 mg. (1/100 grain) of atropine sulfate. Intravenous administration of fluids or blood should be avoided until shock and evidence of acute cor pulmonale have subsided.

Prophylaxis Against Thrombophlebitis: There is good statistical evidence that adequate anticoagulant therapy with coumarin or indandione compounds will prevent thrombophlebitis but this type of treatment is impractical as a routine postoperative or postpartum procedure. However, patients who have had secondary thrombophlebitis or pulmonary embolism in the past have a statistically high enough chance of recurrence if they undergo major operations or obstetrical delivery to justify prophylactic anticoagulant therapy. In institutions where there has been considerable experience with use of anticoagulants, prophylactic anticoagulant therapy may be justifiable after operations on the female pelvis, resection of the stomach or intestine for carcinoma and splenectomy since these operations carry an increased risk of thrombosis. Early ambulation, daily exercise of the feet and legs and adequate hydration probably limit the possibility of thrombosis during the postoperative period to some degree. The use of elastic stockings or bandages during the postoperative period is of questionable value.

REFERENCES

1. Ackerman, R. F., and Estes, J. E: Ann. Int. Med 34:902 (April) 1951
2. Allen, A. W: Surgery 26:1 (July) 1949.
3. Allen, E V., Barker, N. W., and Hines, E A, Jr.: Peripheral Vascular Diseases, W B. Saunders Co, Philadelphia, 1955.
4. Allen, E V., and Brown, G. E.: M. Clin. North America 15:123 (July) 1931.
5. Allen, E. V., Hines, E. A., Jr, Kvale, W. F., and Barker, N. W: Ann. Int Med 27:371 (Sept) 1947
6. Anlyan, W. G, Campbell, F H, Shingleton, W. W., and Gardner, C. E, Jr: Arch. Surg 64 200 (Feb) 1952.
7. Barker, N. W: Circulation 4:613 (Oct.) 1951.
8. Barker, N W.: Arch. Int. Med. 58:147 (July) 1936.
9. Barker, N. W.: Proc Staff Meet, Mayo Clin. 11:513 (Aug 12) 1936
10. Barker, N W., and Counseller, V S. Am J. Obst. & Gynec. 37:644 (April) 1939.

11. Barker, N. W, Nygaard, K. K, Walters, Waltman, and Priestley, J T Proc Staff Meet, Mayo Clin 15·769 (Dec 4) 1940.
12 Barnes, A. R.: J A M A 109 1347 (Oct 23) 1937.
13 Briggs, J. B : Bull Johns Hopkins Hosp 16 228 (June) 1905
14. Buerger, Leo: Internat Clin 3.84, 1909
15 Haimovici, Henry: Circulation 1.225 (Feb.) 1950
16 Homans, John: Surgery 26·8 (July) 1949.
17. Matas, Rudolph: Am. J. Surg. 24.642 (June) 1934
18 Morgan, E. H, Allen, E V., and MacCarty, C S Proc Staff Meet, Mayo Clin. 23:425 (Sept. 15) 1948
19 Norman, I L, and Allen, E. V.· Am Heart J 13:257 (March) 1937
20 Ochsner, Alton, DeBakey, M. E., and DeCamp, P T J A M A 144 831 (Nov 4) 1950
21. Shea, P. C, Jr, and Robertson, R L. Surg, Gynec & Obst 93 153 (Aug) 1951
22 Smith, L. A, and Allen, E. V.: Arch. Surg 41 1377 (Dec) 1940
23. Sproul, E. E.: Am. J. Cancer 34·566 (Dec) 1938
24 Stein, I D, and Rose, O A : A M A. Arch Int. Med 93 899 (June) 1954
25 Thebaut, B. R, and Ward, C S.· Surg, Gynec & Obst 84 385 (April) 1947.
26. Thompson, A. P.: Clin. J. 67·137 (April) 1938
27. Welch, W. H : Thrombosis In. Allbutt, Clifford, and Rolleston, H D A System of Medicine, The Macmillan Co., vol. 6, p 691, London, 1909
28 Wilkins, R W., and Stanton, J R.· New England J Med 248 1087 (June 25) 1953.
29. Wise, W. D., Loker, F. F, and Brambel, C. E · Surg, Gynec & Obst 88 486 (April) 1949
30 Wright, I S, Marple, C. D, and Beck, Dorothy F Am Heart J 36 801 (Dec) 1948.

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Acquired Arteriovenous Fistula, Temporal Arteritis, and Aneurysm

ACQUIRED ARTERIOVENOUS FISTULA

Definition: Arteriovenous communications, short cuts or shunts between the smaller arteries and veins, form a part of the delicate mechanism which regulates circulation. However, when a large artery and vein communicate with one another, the dynamics of the circulation are profoundly disturbed, frequently with serious results. Large arteriovenous communications may be congenital or acquired. In the congenital form, the communications are usually multiple, whereas in the acquired form the communication is single, although Horton and Meyerding reported a case of traumatic arteriovenous fistula in which there were two communicating tracts some distance from each other. Congenital arteriovenous fistulas are considered in detail in the chapter on Varicose Veins

Etiology and Physiology: Acquired arteriovenous fistula usually results from trauma such as a bullet wound or stab wound. It is a relatively common condition. Callander, in 1920, tabulated 444 cases which had been reported in the literature up to that time and many reports of such cases have appeared since.

The deleterious effect which an arteriovenous fistula may have on the heart makes the early recognition of the condition of great importance.[6,7] As pointed out by Lewis and Drury, when the fistulous opening is free, the characteristic signs of aortic reflex ensue in the arterial system, namely, high pulse pressure, capillary pulse, water-hammer pulse, and so forth. The result is a train of events such as results from aortic regurgitation with the development of cardiac enlargement and eventually congestive failure. Holman, in 1924, after analyzing Halsted's cases, determined that in the presence of small arteriovenous communications, changes in the cardiovascular system never developed but invariably they did appear when the fistula was large. Harrison, Dock, and Holman, in 1924, produced arteriovenous fistulas experimentally in animals and found the blood flow through the lungs of such animals uniformly increased to an amount 100 per cent greater than the normal. Smith, in 1931, found a reduction of fifty-eight per cent in cardiac output and an increase of 120 per cent in the coefficient of utilization after repair of fistulas in cases in which cardiovascular symptoms occurred. Kennedy and Burwell, in 1944, demonstrated an increase in cardiac output and blood volume, an increase in oxygen content of the blood near the fistula, a rapid circulation time and an increase in volume

in the arm containing the fistula. They estimated the work of the heart to be increased by about twenty-five per cent by the fistula.

Diagnosis: The diagnosis of an arteriovenous fistula usually is not difficult if the condition is suspected. In most of the cases, attention will be directed toward an enlarged and swollen limb containing prominent or enlarged veins which may be mistakenly thought to be due to primary varicose veins. Closer inspection and palpation of the limb will reveal a pulsating tumor at some point along the larger vessels with an audible bruit and palpable thrill. The thrill and bruit are present throughout the

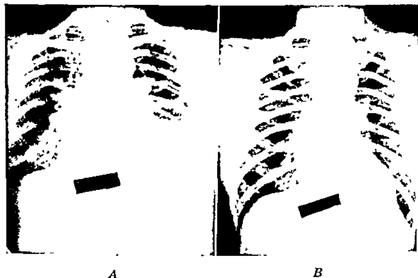


FIGURE 1. Comparison of the size of the heart. *A*, Before operation; *B*, one month after operation (Hines & Waugh Proc Staff Meet, Mayo Clin)

cardiac cycle but are more prominent during systole than during diastole There will be an increased temperature of the surface of the involved extremity, particularly in the region of the fistula. Branham's bradycardiac phenomenon of slowing of the pulse and temporary hypertension may be elicited by occlusion of the fistula. If a bruit is absent and there is a question as to the diagnosis, a puncture of one of the regional veins will reveal arterial blood which is diagnostic of an arteriovenous fistula.[1] Because the arterial blood is shunted directly into the veins, there is usually a vascular deficiency distal to the fistula. The patient may complain of claudication and have symptoms of ischemic neuropathy. Trophic changes, ulcer and even gangrene may develop in the lower part of the extremity. In cases of fistulas of long standing, the picture may be one mainly of congestive heart failure. Factors concerning the fistula which are important in determining its effect on the heart are (1) the size of the fistula, (2) location of the fistula, and (3) duration of the fistula. A small fistula almost never causes any increase in the size of the heart; whereas, a large fistula no matter where it is located will almost always produce eventually marked dilatation of the heart. The determining factor is the amount of increase in work of the heart which results from the fistula. The increase in the size of the heart

is largely the result of dilatation with cardiac hypertrophy being responsible only for a small degree of the increase.

ILLUSTRATIVE CASE: A man, aged fifty-four years, came to the clinic in September, 1935, because of epigastric distress, gaseous indigestion, and dyspnea of six months' duration. The dyspnea had increased gradually so that he was unable to walk more than a block without severe distress Swelling of the right leg had been present for three years In the three months prior to admission he had noted increasing swelling of the left foot and leg

In November, 1922, the patient had been wounded while hunting deer The bullet entered the left hip and traveled across the pelvis into the right inguinal region. He had recovered satisfactorily from this accident except for residual atrophy of muscles of the left calf and left foot-drop caused by injury of the left sciatic nerve He was otherwise entirely well until 1932 at which time the right foot and leg began to swell. In March, 1935, he first noted abnormal pulsation and thrill in the right femoral region.

The patient, when seen for the first time at the clinic, was obviously suffering from a severe degree of cardiac failure He was orthopneic and there was marked edema of the lower extremities There was great enlargement of the region of cardiac dulness and the edge of the liver was palpable 6 cm below the costal border The blood pressure in millimeters of mercury was 154 systolic and 76 diastolic. The pulse rate was 90 beats per minute The right thigh was definitely warmer than the left and there was a thrill and bruit over the right femoral region. When the right femoral artery was closed by deep pressure, the rate of the apex beat of the heart decreased from ninety to sixty beats per minute. A teleoroentgenogram revealed the transverse diameter of the heart to be 21 cm and the diameter of the thorax 32 cm (Fig 1, A). It was felt that in spite of the poor condition of the patient an attempt should be made to repair the fistula. He was hospitalized and put on a regimen to produce dehydration. This included limitation of intake of fluids and the administration of diuretics In less than one week, 13 6 kg (30 pounds) of edema fluid were removed and the patient's cardiac function was greatly improved

Surgical exploration of the region was undertaken by Dr Pemberton and Dr. Waugh on September 16, 1935 A longitudinal incision was made in the right inguinal region; the inguinal ligament was divided and the external iliac and femoral vessels were exposed There was an arteriovenous fistula about 2 cm. in diameter between the femoral artery and vein exactly at the point at which the profunda femoris branched off from the main vessel

About 4 cm. above the inguinal ligament a tape was placed around the external iliac artery and another around the vein, so that they could be used if necessary to control hemorrhage during the operation These two vessels were huge, measuring about 5 cm in diameter, but were constricted as they passed below the inguinal ligament. The femoral artery and vein were exposed below the fistula and tapes were placed around them for emergency purposes. The femoral artery below the fistula was small but the vein was dilated to three or four times its usual diameter.

In an attempt to expose the communication between the artery and vein an opening was made in the femoral artery which necessitated its ligation just below Poupart's ligament The artery was then opened through a longitudinal incision and the communication between the femoral artery and vein was exposed and sutured with silk. There was good retrograde bleeding from the distal ends of the femoral and profunda femoris arteries and these two vessels were ligated at their point of junction.

Excepting the fact that in the right calf there was severe pain of an ischemic, neuritic type, which lasted several days, the patient made an uneventful convalescence and was dismissed from the clinic one month after operation. At the time of his dismissal the size of the heart had decreased greatly as compared with that prior to operation (Fig. 1, *B*); the blood pressure in millimeters of mercury was 130 systolic and 90 diastolic and the pulse pressure was normal; the pulse rate was ninety beats per minute. Pain and dyspnea on exertion did not occur and the patient could walk several blocks without difficulty.



FIGURE 2 Arteriogram showing fistula between femoral artery and vein: *a*, Bird shot; *b*, femoral artery; *c*, femoral vein; *d*, saccular enlargements in the femoral vein (Horton: Am. J. M. Sc. 187:649 [May] 1934.)

Treatment: In every case of traumatic arteriovenous fistula an attempt should be made to repair the fistula surgically. The chief reasons for permanently closing traumatic arteriovenous fistulas are (1) the prevention and relief of chronic venous insufficiency in the involved extremity, (2) the prevention of or relief of heart failure and (3) the prevention of increased growth of the involved extremity when the patient is at an age when the epiphyses have not closed. Before attempting repair it is well to wait for three to six months after the inception of the fistula to allow time for establishment of collateral circulation. Also, the delay makes dissection easier and permits subsidence of infection. The Moszkowicz-Matas[10,16] hyperemic test is useful in determining the status of the collateral circulation. Such a test is carried out by elevating the extremity and allowing it to become as ischemic as possible. An elastic bandage is then applied in

circular fashion from the digits to the level of the lesion. The artery proximal to the lesion is occluded by compression preferably by a clamp or by digital pressure. A tourniquet or inflated blood pressure cuff may be used but has the disadvantage of interfering to some extent with the collateral circulation. The bandage is removed after five to ten minutes while the artery still remains occluded. The extent and rapidity of development of the hyperemic flush which follows removal of the bandage is an index of the efficiency of the collateral circulation.

If possible, the site of the fistula should be determined by arteriography before surgical exploration is attempted (Fig. 2) The arteriographic demonstration of an arteriovenous fistula at the clinic was first carried out by Horton and Ghormley. The technic is as follows: A local anesthetic agent is infiltrated around either the brachial or the femoral artery. A 20 gauge needle on a 20 cc. syringe is inserted into the artery and the artery is closed either by the use of a blood pressure cuff, if the injection is being made into the brachial artery or by digital pressure just proximal to the needle when the injection is being made into the femoral artery An injection of 10 to 12 cc. of diodrast is then made into the artery The diodrast is injected promptly and four or five roentgenograms are made in rapid succession while the artery is still closed. The interpretation of the films depends on the fact that when the injection is made into the normal arterial tree diodrast does not appear in the veins in the first film after injection if the portion of artery proximal to the point of injection is kept closed. The demonstration of the diodrast in the first film with the artery closed, therefore, is diagnostic of an arteriovenous fistula The amount of filling by the diodrast on the venous side is proportional to the size of the fistula. In recent years thirty-five or seventy-five per cent diodrast has been the preferred medium for arteriography in this country.

No single surgical procedure is adaptable to all cases of arteriovenous fistula. The ideal procedure would be to excise or obliterate the fistulous tract allowing the lumen of the artery and vein to remain patent. It is important, after careful dissection, to correlate the anatomic findings with the condition of the collateral circulation before determining the operative procedure most applicable. Ligation of the artery proximal to the fistula alone is not satisfactory. This might relieve the load on the heart somewhat, but usually it diminishes the circulation to the tissues below the fistula so greatly that gangrene results. Excision of a segment of the artery and vein, including the communications and quadruple ligation, has given satisfactory results in certain cases in which the ideal procedure of preserving the lumen of the artery and vein could not be performed.

TEMPORAL ARTERITIS (CRANIAL ARTERITIS)

Temporal arteritis is a regional arteritis representing a clinical syndrome which is apparently distinct from periarteritis nodosa. It generally affects elderly persons and is characterized by an arteritis usually involving the temporal arteries and is accompanied by moderate toxic symptoms, particularly anorexia, malaise, fever, night sweats, loss of weight, anemia, and leukocytosis. The retinal and cerebral arteries may be involved. In one

patient a radial artery was involved in the same process as the temporal artery.

Jonathan Hutchinson first described a case of temporal arteritis in 1890. It was not until 1932 that other cases were reported. The syndrome was described by Horton, Magath, and Brown in 1932 and in 1934. At that time they had not found Hutchinson's case in the literature.

Etiology: The cause of the peculiar process affecting the cranial arteries is unknown. In the carefully studied series reported by Horton, Magath, and Brown cultures made from the resected arteries in five cases gave negative results. Inoculation of animals gave negative results and studies of numerous microscopic sections failed to reveal the presence of the *Mycobacterium tuberculosis* and *Treponema pallidum*. The results of agglutination tests for typhoid, paratyphoid, undulant fever, and tularemia were negative. Although the appearance of the lesion pathologically is suggestive of an inflammatory process of low grade, the changes may be on a degenerative basis due to changes in the vasa vasorum. In almost all reported cases of temporal arteritis the patients have been more than fifty-five years of age and usually more than sixty-five. There is no predilection for either sex.

Pathology: The characteristic pathologic picture is one of a chronic periarteritis and arteritis. The intima is greatly thickened and the media is necrotic in some regions. In the portions of the media in which repair is taking place, there is granulomatous tissue which contains numerous giant cells. Nodular regions along the adventitia consist of collections of round cells around the vessels of the vasa vasorum. The aneurysmal sacs, associated with lesions of periarteritis nodosa, are seldom found in the lesion of temporal arteritis.

Diagnosis and Prognosis: The presenting symptom is always headache, usually of a severe type and often worse during the night than during the day. Jarring of the head, coughing, sneezing, and chewing greatly aggravate the pain. Difficulty in chewing food and visual disturbances, particularly those involving loss of portions of visual fields and occasionally complete blindness, may be predominant symptoms. Accompanying these symptoms, or occurring shortly after their appearance, are signs of low-grade infection. Fever, malaise, and exhaustion are outstanding. Mild leukocytosis and elevation of the sedimentation rate usually are present. As the disease progresses, moderate anemia develops. From two to five weeks after the onset of symptoms the characteristic objective features of the disease, namely, tortuosity and prominence and extreme tenderness of the temporal arteries, become evident. Along the course of the arteries small nodules can be palpated. As the process continues, the pulsation in the artery is diminished and eventually the lumen may be occluded. The temporal or occipital arteries are involved although in one case which I encountered, the same process occurred in a section of the radial artery. In many untreated patients involvement of branches of the ophthalmic artery occurs.

The disease tends to be self-limiting and runs a course of four to six months. Complete recovery resulted within two years after the onset of symptoms in all of the cases so far reported (1955). During this time,

however, the patients were more or less disabled because of the severe headache and unpleasant systemic reaction. A few patients have had relapses. Visual impairment is an important symptom because when loss of vision occurs, it is almost always permanent.

ILLUSTRATIVE CASE: A married woman, aged sixty-nine years, was admitted for the first time to the clinic in February, 1935 Her chief complaint was pain which had been present for two months over her right eye For six weeks the pain had been constant and had been projected from the right eye toward the right side of the head and into the neck and shoulder Ten days before admission her temporal vessels on the right side had become noticeably engorged. Also she had complained of anorexia, loss of weight, and nausea She had experienced some fever and considerable general weakness The general examination gave essentially negative results except for prominence of the temporal vessels and redness over the right temporal artery with severe tenderness along the course of the artery During her stay of five weeks in the hospital the temperature by mouth ranged from 36 1 to 38 3° C (97 to 101° F), the pulse rate ranged from 70 to 110 beats a minute The blood pressure on admission in millimeters of mercury was 145 systolic and 95 diastolic Neurologic examination gave objectively negative results as did that of the cerebrospinal fluid The number of leukocytes varied from 9000 to 14,800 per cubic centimeter of blood; erythrocytes, 4,330,000 The concentration of hemoglobin was 11 7 Gm per 100 cc. of blood Repeated urinalyses gave negative results Likewise, cultures of the blood and agglutinations for undulant fever, typhoid fever, and paratyphoid fever gave negative results Roentgenograms of the head and thorax were normal. A segment of the right temporal artery was removed for biopsy, sections of which revealed a subacute arteritis and periarteritis with proliferation of the intima which almost occluded the lumen. There was much destruction of the media and many giant cells were present.

Treatment was started with potassium iodide, giving as much as 50 drops of the saturated solution four times daily This large dose was well tolerated Codeine and aspirin were given for the relief of pain The patient was given 0 3 Gm of neoarsphenamine intravenously each week After the removal of the artery the headache was greatly improved On the eighth day after admission, the patient began to complain of pain in the left forearm and it was soon observed that an arteritis was developing in the left radial artery The distal third of the artery became tender, red, and thickened A section of the artery was removed and the microscopic picture of the sections was similar to that of the portion of temporal artery previously subjected to biopsy but the process was more acute in the radial artery Removal of the radial artery relieved the pain in the arm At the time of the patient's dismissal, thirty-eight days after admission, she did not have fever, her strength was much improved, and the headache had for the most part disappeared After returning home the patient continued to take the potassium iodide and a dose of 0 3 Gm of neoarsphenamine was administered each week for six weeks Six months after dismissal, in a report from her physician it was stated that the patient was almost entirely relieved of symptoms and that she had been afebrile for three months.

Differential Diagnosis: Temporal arteritis should be distinguished from periarteritis nodosa because of the grave prognosis in the latter condition. The regional nature of the temporal arteritis, contrasted with the more general involvement and the more severe systemic symptoms of periarter-

itis nodosa should serve to distinguish the two conditions. In the early stages of periarteritis nodosa the diagnosis is usually obscure because of the absence of involvement of large and visible arteries. If difficulty is experienced in the differential diagnosis a positive diagnosis of temporal arteritis can be made after biopsy of a portion of involved artery. Migraine should not be easily confused with temporal arteritis as in the latter case the headache is usually continuous and systemic symptoms soon occur. There may be some difficulty in distinguishing between temporal arteritis and a headache designated by Horton, MacLean and Craig as "erythromelalgia" of the head. In the latter condition the headache is of a throbbing type and there are distention and congestion of the vessels in the temporal region. However, the distention and congestion occur only during the headache and the arteries are not tender and nodular as in cases of temporal arteritis. Furthermore, the systemic signs of infection do not occur if the erythromelalgia type of headache is present.

Treatment: Until recently, relief of the distressing headache and general supportive measures were the main considerations in treatment. Salicylates and soporifics should be used when indicated but injudicious use of narcotics should be avoided because of the chronicity of the disease. In my experience neither the antibiotics nor the sulfonamides have been of value in the treatment for this disease. Excision of the involved segment of the artery has been advised as a curative measure. This may relieve the pain but seldom does it have any effect on the general manifestations of the disease; neither will it prevent involvement of other cranial or intracranial arteries.

The great therapeutic need is some measure to prevent the occurrence of loss of vision. Both cortisone and corticotropin usually control the local and systemic symptoms and if given in adequate dosage will almost always prevent visual complications if such have not occurred before treatment is started. I have initiated treatment with fairly large amounts of these hormones. The usual program is to administer 300 mg. of cortisone in divided doses for the first twenty-four hours of treatment and 150 to 200 mg. daily thereafter for six weeks. It is advisable to taper off the dosage after symptoms are under control and to continue suppressive treatment with orally administered cortisone in doses of 25 to 75 mg. a day or meticorten in doses of 5 to 15 mg. a day until the disease has run its natural course. This may require from three to nine months of suppressive treatment.

ANEURYSM

General Considerations: Aneurysms of the large arteries of the trunk and extremities have been recognized since the time of Galen. Cerebral aneurysms, because of the obscurity of symptoms and lack of objective signs, have been recognized only in comparatively recent times. Descriptions of the pathologic characteristics of aneurysm abound in the literature and etiologic factors have been considered at length but there have been few studies from the physiologic standpoint which is of great importance when therapy is to be considered.

All true aneurysms have at least one layer of the arterial wall forming the sac. False aneurysms are hematomas which result from rupture of the arterial wall. Aneurysms may be single or multiple. In the large arteries of the trunk aneurysms are usually single whereas in the cerebral arteries and arteries of the extremities they are frequently multiple. The etiologic factor and the difficulty of diagnosis are dependent on the situation of the aneurysm. The majority occur within the thorax. In the series of 596 cases of aneurysm at the Mayo Clinic which were reviewed by Mills and Horton, the incidence according to situation was as follows: Head, twenty-four per cent; thorax, fifty-six per cent; abdomen, thirteen per cent, and extremities, three per cent.

Aneurysms may be classified according to their etiology, as syphilitic, arteriosclerotic and congenital or mycotic, or according to situation as intracranial, abdominal and so forth. The classification of aneurysms into different groups because of minor anatomic differences as to shape and form of the aneurysmal sac is of little practical importance. Of more importance is the situation of the aneurysm as regards collateral circulation and accessibility.

Etiology: Anything that produces weakening of the wall of an artery may result in the formation of aneurysm. The situation of the aneurysm is a determining factor in its etiology. Aneurysms of the arch of the aorta are usually syphilitic inasmuch as it is this part of the vascular tree which is most commonly affected by syphilis. The farther the aneurysm is from the arch of the aorta, the less frequently is syphilis an etiologic factor and the more important are arteriosclerotic changes and congenital defects. Good evidence of this is furnished in the series reported by Mills and Horton in which syphilis was the etiologic factor in seventy per cent of the cases of aneurysm of the thoracic aorta and in only nine per cent of those of aneurysms of the abdominal aorta. Infection is an infrequent cause of aneurysms as the arterial wall is highly resistant to infection by encroachment from adjacent tissues. Embolic or mycotic aneurysms may be associated with bacterial endocarditis in which case the initial lesion is probably due to embolism of the vasa vasorum. Trauma plays an important rôle in the occurrence of aneurysms of the extremities and those developing after gunshot and stab wounds in other parts of the body. Congenital defects are of importance in aneurysms of the cerebral arteries and in the smaller arteries such as in the palmar arch.

Pathologic Characteristics: The pathologic characteristics of an aneurysm depend on the extent and nature of the underlying lesion. The important change takes place in the media which is the main supporting part of the arterial wall. The weakening of the media results in a dilatation forming a sac which in the diffuse type is covered by all of the layers of the arterial wall. In the saccular form, the process of dilatation disrupts the layers and both muscular and elastic tissue are replaced by fibrous tissue. As the blood stream is slowed, mural thrombi form on the wall of the sac and may result in complete occlusion. Closure by thrombosis is more likely to occur in the saccular type than in the diffuse type. The microscopic

appearance of a section of the wall of the aneurysm will depend on the underlying etiologic factor.

Signs and Symptoms: Except for the observable pulsating mass and the bruit, aneurysms produce most of their characteristic signs and symptoms through pressure on contiguous structures. Consequently, the signs and symptoms are dependent on the situation of the aneurysm and are best considered from this standpoint.

Cerebral Aneurysm: The signs and symptoms of a cerebral aneurysm do not form a characteristic picture which can be recognized very often with certainty. However, more careful correlation of the clinical picture with the findings at necropsy has resulted in recognition of certain significant signs and symptoms which materially aid in making a correct diagnosis of a condition which was described in the early textbooks of medicine as being impossible of diagnosis ante mortem. Aneurysms may occur in any of the cerebral arteries but they are commonest in the arteries of the circle of Willis. Often the diagnosis cannot be suspected until rupture occurs with leakage into the subarachnoid space, presenting the symptoms of severe basilar headache, vomiting, and drowsiness, associated with a stiff neck and a bloody spinal fluid. The sudden onset of a unique, severe headache in a person who has hypertension always should be considered as due to a ruptured aneurysm until proved otherwise. When leakage or rupture has not occurred, the findings will depend on the size and situation of the aneurysm in relation to contiguous structures The picture may be similar to that of a neoplasm, particularly in cases of supraclinoid aneurysm which give findings similar to those associated with basofrontal neoplasms, such as mental disturbances, changes in the visual fields and ophthalmoplegia. A syndrome produced by an aneurysm of the internal carotid artery includes loss of the sense of smell, ptosis of the eyelid, dilation of the pupil and ophthalmoplegia. Because of pressure on the cavernous sinus, there may be congestion of the vessels of the eye and swelling of the veins of the face. The fifth nerve may be involved with pain in the face. Noises in the ear and sometimes impaired hearing on the side of the aneurysm occur.

The absence of a bruit in most cerebral aneurysms or the absence of characteristic roentgenologic findings makes uncertain the recognition of the lesion as one caused by an aneurysm. The routine roentgenologic findings considered most characteristic are calcification in the wall of the aneurysm and unilateral enlargement of the optic foramen. Erosion of the carotid canal or unilateral erosion of the sella turcica is very suggestive of aneurysm. Arteriography, using a suitable opaque medium such as diodrast, may allow visualization of an intracranial aneurysm in the carotid system.

Aortic Aneurysms: The symptoms of aneurysm of the thoracic aorta are variable and depend on the rapidity with which the aneurysm dilates and the encroachment of the pulsating mass on surrounding structures. Symptoms may not be present even when a fairly large aneurysm exists.

Pain is a frequent symptom. It is usually substernal and commonly referred to the back, particularly to the left scapular region, and sometimes to the shoulder, arm, or neck. It may be severe and may occur while the

patient is at rest or as a result of effort. It is usually of longer duration than typical angina pectoris. Obstruction of the superior vena cava or subclavian vein may occur; dysphagia may result from pressure on the esophagus; dyspnea and stridor, from tracheal or bronchial compression, and hoarseness and a brassy cough, from pressure on the recurrent laryngeal nerve, may be present. The arms may be numb.

The physical signs are not diagnostic and may be absent. The region of percussion dulness may be widened over the basal portion of the heart or in the left posterior part of the thorax and diastolic heaving of the wall of the thorax may be noted in these regions. In cases of advanced disease the wall of the thorax bulges anteriorly or posteriorly and the pulsatile tumor may be clearly visible. A systolic murmur may be heard over the aneurysm but is not always present. The presence of a tympanitic aortic second sound in a person less than fifty-five years of age who does not have hypertension or evidence of advanced arteriosclerosis is highly suggestive of early syphilitic aortitis. A systolic murmur in the region of the aorta localized or transmitted to the carotid arteries also is a suggestive sign. The electrocardiogram is not of value in making the diagnosis of aneurysm of the thoracic aorta or early syphilitic aortitis

The most valuable and conclusive procedure in diagnosis is roentgenoscopy and in many cases the aneurysms are discovered only by this type of examination.

The principal lesions to be differentiated from aortic aneurysms in the thorax are intrathoracic tumors and aneurysms of the pulmonary arteries. The distinction usually can be made on roentgenoscopic examination. Bronchoscopy or esophagoscopy should never be done if doubt exists concerning the diagnosis because of the danger of rupture if the lesion is an aneurysm.

The diagnosis is not difficult except in cases in which pulsation is not noted at roentgenoscopy. The symptoms, usually cough, hemoptysis, and substernal thoracic pain, are not helpful in the diagnosis Clubbing of the fingers almost never occurs, and cyanosis is a late symptom of associated congestive heart failure. On physical examination a harsh systolic murmur may be heard at the left border of the sternum near the second or third intercostal space and occasionally a diastolic murmur also is heard in the same region. A thrill may be felt in about a third of the patients. The murmur and the thrill may be influenced or caused by associated cardiovascular defects. The electrocardiogram shows right axis deviation in the majority of cases and may be of some help in the differential diagnosis. The roentgenographic or roentgenoscopic demonstration of a pulsating mass in the hilar region which is separate from the aortic shadow is the most dependable clinical means of establishing the diagnosis Special roentgenologic methods, such as arteriography and angiocardiography, are usually of no additional value in establishing a diagnosis except in the rare case in which the aneurysmal mass does not pulsate. The demonstration of peripheral, linear calcification in the mass on roentgenographic examination may indicate that the mass is an aneurysm. This sign may be especially helpful in the diagnosis of the nonpulsating aneurysm.

Abdominal Aneurysm: Abdominal pain and the presence of an abdominal mass noted by the patient are the two symptoms of aneurysm of the abdominal aorta most frequently encountered. The pain may be persistent or intermittent. Severe, persistent pain may be present even when rupture has not occurred and is due, probably, to a periaortic inflammatory type of reaction sometimes found in patients with abdominal aortic aneurysms. The pain of abdominal aortic aneurysm commonly is a diffuse type of distress in the middle and lower portion of the abdomen or in the lower part of the back. Pain tends to be more prominent on the left side and to extend down the left side of the abdomen. Sometimes the pain is equally distributed on both sides of the abdomen and back with extension into both groins and anterior regions of the thighs.

The one common physical sign is an expansile, pulsatile mass in the abdomen. The bulk of the mass is located usually in the left side of the abdomen. The diagnosis of an aneurysm should not be made solely on the basis of this physical finding unless the mass can be grasped by deep pressure with both hands and localized, bilateral, expanding pulsation can be felt. Nervous patients frequently complain of abdominal throbbing and pulsation and in such patients a prominent pulsation may be felt in an aorta of normal size. Patients who have lordotic spinal columns or elderly persons with sclerotic, tortuous aortas may have palpable abdominal pulsations which simulate the pulsations in an aneurysm. A thrill or bruit is present over an aneurysm in only about half of the patients and its presence or absence does not help much in the diagnosis.

It is significant that a third of the patients in Estes' group did not have symptoms referable to the aneurysm at the time of examination. The aneurysms of these patients were discovered either on routine physical examination or incidentally by x-ray examination or surgical exploration carried out because of other complaints presented by the patient. This emphasizes the value of careful palpation of the abdominal aorta in the course of physical examination of all older patients.

Often the aneurysmal sac is partially or almost completely filled with old and new blood clots, and these may affect the degree of pulsation which can be felt as well as the finding on roentgenographic examination. Occasionally, the renal artery may be included in the aneurysmal sac, and the blood flow through the renal artery may be impeded by the blood clot in the aneurysm or by atheromatous plaques. I have observed two patients in whom this type of involvement of the renal artery apparently caused moderately severe hypertension. The commonest serious complication is leaking or rupture of the aneurysm. Erosion of vertebrae and pressure on neighboring nerve trunks or organs are rare occurrences.

The diagnosis is not difficult and usually can be made on the basis of the findings on physical examination. A plain roentgenogram of the abdomen ordinarily will show evidence of a soft-tissue mass, of a calcified plaque or, in some cases, of a curvilinear area of calcification which is characteristic of an aneurysm of the abdominal aorta. Aortography is not essential for diagnosis although it is helpful in the evaluation of treatment. The aortogram will give information of importance concerning the relationship of

arterial trunks (particularly the renal and mesenteric arteries) to the aneurysm and the patency of these arteries. The presence and size of an intraluminal blood clot is usually well demonstrated in the aortogram. These blood clots may give a misleading picture in that they may almost entirely fill even a very large aneurysm and may cause the lumen to appear normal or nearly normal in size in the aortogram. In such a situation the location of the walls of the aneurysm may be apparent from the curvilinear area of calcification in the wall previously mentioned as being shown in the roentgenogram. This area may be several inches away from the lumen as demonstrated in the aortogram. Occasionally, when physical examination and roentgenographic findings are inconclusive, abdominal exploration may be necessary to confirm or disprove the diagnosis.

Aneurysms of Larger Peripheral Arteries: The diagnosis of aneurysms of the popliteal and femoral arteries is usually easily made by the palpation of a pulsating mass the transverse diameter of which is definitely greater than the diameter of the artery should be Expansion of the artery on pulsation can be felt if the thumb and forefinger are placed on each side of the mass. A short systolic bruit with a single pitch can be heard frequently but not always with the stethoscope. In roentgenograms arteriosclerotic aneurysms are often revealed by the irregular line of calcium at their margins. In doubtful cases the diagnosis can be confirmed by arteriography but this is rarely necessary Arteriovenous fistulas can be distinguished by the thrill, multiple pitched machinerylike bruit, greatly increased venous pressure and increased content of oxygen in blood drawn from a distended vein near the fistula Sarcomas or other such solid tumors may pulsate but never to the same degree as an aneurysm, and pulsating tumors are rare in Scarpa's triangle and the popliteal space.

Complications of popliteal aneurysms occur frequently and may be serious, leading to loss of an extremity or loss of the life of the patient. The most serious complications are embolization distal to the aneurysm from a mural thrombus in the aneurysm, leaking of the aneurysm and pressure from the aneurysm on the neighboring vein or nerve. Acute occlusion of the aneurysm may occur from thrombosis and may result in severe ischemia with development of gangrene and loss of the extremity

A study made by Gifford, Hines and Janes of 100 popliteal aneurysms seen in patients at the Mayo Clinic disclosed forty-nine complications at the time that the patients were first seen at the clinic. Serious complications developed in thirteen of fifty-one originally uncomplicated aneurysms within a few years. Many of the aneurysms had more than one complication. Twenty of the 100 aneurysms resulted in amputation of the extremity either at the patient's initial visit or shortly afterward. The majority of the amputations were done because of occlusion of the aneurysm by a thrombus or because of distal embolization resulting in gangrene in the extremity.

Treatment: An aneurysm of the extremities often may be excised successfully. When the remaining portion of the artery is in reasonably good condition and the gap is not greater than three or four inches, it is possible to bridge the gap and thus restore the continuity of the artery. The condi-

tion of the collateral circulation must be given careful consideration before surgical treatment is attempted. Unfortunately, aneurysms of the peripheral arteries are usually on an arteriosclerotic basis and the arteriosclerosis also affects the collateral arteries and reduces the potential collateral circulation. The collateral circulation can be estimated satisfactorily by employing the Moszkowicz-Matas test previously described in the section on "Treatment of Acquired Arteriovenous Fistula." If the thrombus has occluded the artery completely and if there is little evidence of ischemia of the distal portion of the extremity, the collateral circulation can be assumed to be adequate. Aneurysms of the peripheral arteries may leak and aneurysms of the popliteal artery frequently produce pressure on the adjacent nerve which may result in paralysis. For this reason, it is justifiable to attempt excision of the aneurysm if the collateral circulation is reasonably adequate. It is not wise to wait too long for a collateral circulation to develop, for the possibility of paralysis occurring during the waiting period must be considered. Venous thrombosis in accompanying veins as the result of pressure and irritation may complicate the situation.

Surgical treatment is the only satisfactory way of dealing with aneurysms of the popliteal artery. This treatment should be carried out before complications develop whenever possible, inasmuch as the risk of complications after surgical treatment, particularly gangrene and loss of an extremity, is higher if complications have already occurred before surgical treatment is done.

The data of Gifford, Hines, and Janes show that subsequent amputation is three times more likely to occur in the extremities with popliteal aneurysms which are not treated surgically. When spontaneous occlusion of the aneurysm has not occurred, the procedure of choice, in my opinion, is lumbar sympathectomy with immediate surgical removal of the aneurysm. The defect thereby produced in the popliteal and lower femoral artery may be repaired with a homograft; however, the placing of a graft in an area subjected to so much strain from bending of the knee joint in ordinary physical activity makes it likely that the graft will not be satisfactory over a long period. Furthermore, the results of simply removing the aneurysm have been so satisfactory in our experience that the addition of the homograft may be of little help beyond establishment of the collateral circulation which may become established naturally after removal of the portion of the artery containing the aneurysm.

Methods of obliterating aneurysms of the aorta and of the larger arteries of the trunk by electrolysis and by insertion of foreign bodies are not very satisfactory. From the medical standpoint, a program and medication for reducing the blood pressure, if hypertension is present, and the avoidance of overexertion may afford considerable protection to the patient. If syphilis is present proper treatment should be instituted and if congestive failure of the heart is present the usual relevant methods of treatment should be employed.

Resection of arteriosclerotic aneurysms of the abdominal aorta and restoration of the aortic pathway by replacement with preserved homologous aortic grafts has been carried out successfully in a number of instances in

the past two or three years. Patients who have been treated in this manner have not been followed long enough to know the effect of such treatment on the long-term prognosis. It is known that surgical treatment may be a lifesaving measure for some patients and that many patients have been relieved of symptoms and have lived for many months longer than they could have lived without such treatment.

In certain cases of cerebral aneurysm, ligation of the homolateral carotid artery in the neck can be carried out successfully. It is well to remember that among young persons the carotid artery may be ligated without risk, whereas among persons whose ages are greater than thirty-five years the risk of hemiplegia developing increases in proportion to the age. Before attempting ligation, it should be demonstrated that the patient can withstand manual occlusion of the artery for as long as thirty minutes The operation should be performed under local anesthesia and a trial ligature should be placed around the artery If vertigo, faintness, weakness, or numbness should occur, the ligature should be removed and permanent closure should be attempted at a later date if sufficient collateral circulation can be developed.

REFERENCES

1. Brown, G E. Arch Surg 18,807 (March) 1929
2. Callander, C. L. Johns Hopkins Hosp Rep 19 259, 1920, Ann Surg 71 428 (April) 1920
3. Estes, J E, Jr Circulation 2 258 (Aug) 1950
4. Gifford, R W., Jr., Hines, E A, Jr, and Janes, J M Surgery 33 281 (Feb) 1953
5. Harrison, T R, Dock, W, and Holman, E Heart 11 337 (Dec) 1924
6. Hines, E A, Jr, and Waugh, J M Proc Staff Meet, Mayo Clin 11 545 (Aug 26) 1936.
7. Holman, Emile Ann Surg 80 801 (Dec) 1924
8. Horton, B T, and Ghormley, R K Proc Staff Meet, Mayo Clin 9 761 (Dec 12) 1934, Surg, Gynec & Obst 60 978 (May) 1935
9. Horton, B T, MacLean, A R, and Craig, W McK Proc Staff Meet, Mayo Clin 14 257 (April 26) 1939
10. Horton, B T, Magath, T B, and Brown, G E Proc Staff Meet, Mayo Clin 7.700 (Dec 7) 1932
11. Horton, B T, Magath, T B, and Brown, G E Arch Int. Med 53 400 (March) 1934
12. Horton, B T, and Meyerding H W Proc Staff Meet, Mayo Clin 14,4 (Jan 4) 1939.
13. Hutchinson, Jonathan Arch Surg (London) I 323 (April) 1890
14. Kennedy, J A, and Burwell, C S Am Heart J 28 133 (Aug) 1944
15. Lewis, T., and Drury, A N Heart 10 301 (Oct.) 1923
16. Matas, Rudolph: Ann Surg 53 1, 1911, J A M A 63 1441 (Oct 24) 1914
17. Mills, J H, and Horton, B T Arch Int Med 62 949 (Dec.) 1938
18. Smith, C. Arch Int. Med 48 187 (Aug) 1931

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Arteriosclerosis Obliterans

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obstructive lesions may be diffuse, scattered, or sharply localized, they frequently produce a reduction in blood flow to essential tissues such as those of the brain, heart, or kidneys, or to the legs, below a critical level, thus jeopardizing the well-being or life of the individual affected Atheromatous plaques may be demonstrated in at least half of patients dying at age fifty, and as many as ninety per cent of patients who attain the age of seventy-five. This condition assumes its importance by virtue of high morbidity as well as severity of consequence. It is estimated that in this country at least sixty per cent of those who die after attaining an age of fifty years will do so as a direct consequence of some cardiovascular-renal defect, and an undetermined but major percentage of these deaths will be the result of degenerative changes of the arteries, while another large group will, during their lives, require treatment for similar disorders.

The present discussion will largely relate to the effects of this disease upon the legs; many of the principles discussed may be applied in varying degree to similar processes occurring elsewhere in the body.

Pathology and Pathogenesis: The fundamental lesion of arteriosclerosis obliterans is the atherosclerotic plaque, which reduces blood flow to such a degree that the peripheral tissues do not receive sufficient blood to supply their metabolic needs.

Within the scope of this article the sites of predilection are the abdominal aorta, the iliofemoral trunks and their major branches. In a study of legs in which the disease had progressed to a degree which necessitated amputation, occlusion was demonstrated in every case. Ninety per cent of the limbs examined showed two or more sites of occlusion, and the average was found to be eight per leg. In this group of amputations—many below the knee—the popliteal was the artery most frequently involved, and this was followed by the anterior tibial artery. The peroneal and posterior tibial vessels were less frequent, but still common sites of occlusion. The distal third of the femoral artery just before its bifurcation is another site of predilection.

Morphology: Atherosclerosis represents a disease of the intima and media of the large and medium-sized arteries, characterized by focal thick-

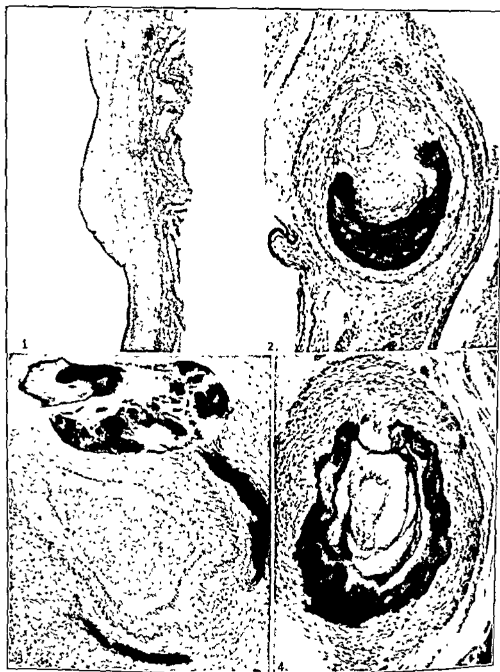


FIGURE 1 × 20 [illegible] artery

[illegible] ns Cross section of a peripheral [illegible] the
artery sh[illegible] ssue
lumen [illegible] the
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not clearly seen.

FIGURE 3 × 167 Arteriosclerosis obliterans Cross section of a peripheral artery showing some thickening of the intima but this is not as marked

enings in which lipids may be demonstrated. Each lesion represents the resultant of two processes; a tendency toward lipid deposition, in which subsequent necrosis occurs, and a tendency toward fibroblastic proliferation with the laying down of a collagenous substance Either or both of these processes impinges upon the lumen of the artery involved.

The earliest known sign of atherogenesis is the appearance in the thoracic aorta of "fatty flecks." These may appear at any time after about the ninth year of age, and appear on examination of the aorta as tiny, oval or round, yellow spots, projecting slightly above the level of the aorta With progression they may coalesce to extend as streaks running longitudinally along the wall of the aorta, usually along the posterior wall In most patients these "fatty flecks" will regress in time, leaving behind no scar, except in some a small amount of fibrosis. As the individual becomes older the lesions appear lower on the aortic axis and extend into vessels elsewhere in the body. As the lesion progresses it appears in gross as a tiny yellow intimal cushion, projecting slightly into the lumen of the vessel. Microscopically it appears to be accumulating lipid. This collects intracellularly in the globular macrophages known as "foam cells," and in an extracellular phase as a scattering of sudanophilic fat droplets within the intimal ground substance. Overlying this focal accumulation is seen a pearly-gray fibrous cap of connective tissue in which the element of fibroblastic proliferation may already be discerned

The lipid phase is more obvious in lesions of the lower aorta, while the fibrotic element predominates more commonly in the legs. However, both elements are present in every lesion. It has been noted clinically that lipid lesions are commoner in the legs of diabetics than in nondiabetics. As the lesion advances, accumulation of lipid is progressive, with death and destruction of the "foam cells," necrosis of the area, and ulceration through the endothelial surface into the lumen of the vessel. The lesion also results in degeneration and fragmentation of the internal elastic membrane, followed by degeneration of the underlying media. In both media and intima an inflammatory reaction ensues with degeneration and repair. This is associated with proliferation of the fibroblastic elements, resulting in the slow, gradual formation of atherosclerotic plaques.

Complete occlusion of the lumen frequently occurs. It may be the result of continued growth of an atherosclerotic plaque, or may result from thrombosis at the site of ulceration. A third type of occlusion follows hemorrhage into the vessel wall, producing a bulging into the lumen at the site of the degeneration The final occlusion may be sudden or gradual.

When the vessels themselves are examined in gross they are found to be elongated, tortuous, and lacking in elasticity. They are firm and irregular,

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as in Fig 2 The laminae elastica are here shown clearly being obliterated only where degeneration of a large area has taken place The degenerative and calcific changes are most pronounced in the media suggesting the so-called "Monckeberg sclerosis."

FIGURE 4 × 170 Arteriosclerosis obliterans A somewhat different type of involvement in which the intima and intermediary layers have been destroyed and replaced by calcification The muscularis is relatively intact.

and in advanced cases may contain hard plaques or a brittle shell of calcium. The legs may show secondary effects of ischemia; the skin becomes thin and atrophic, the muscles atrophy, and the nails become stunted, thickened, and brittle. Osteoporosis and, in severe cases, gangrene of the toes or even of the foot may develop. Infections are resistant to treatment and frequently spread into the foot and leg or become indolent, failing to heal for weeks or even months.

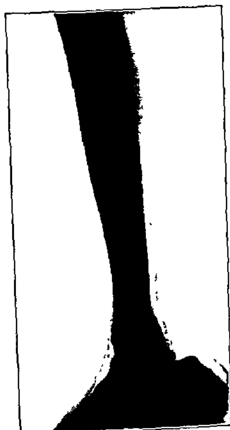


FIGURE 5 Arteriosclerosis obliterans X-rays of leg and foot showing definite evidence of arteriosclerosis of both the posterior tibial and dorsalis pedis arteries This finding is of value in establishing the diagnosis but does not determine whether the vessels are patent or closed For this, other tests including palpation, oscillometric readings, and sometimes arteriographic studies, etc, are essential.

Pathologic Physiology: The larger arterial trunks which carry most of the blood have been shown to be prone to narrowing and occlusion by the atheromatous process The effect on function may be regarded as an equilibrium between the pathologic process which compromises the lumen, and the compensatory processes which may arise spontaneously in the patient, or may be brought about by therapy; occlusion and spasm are balanced against the development of useful collateral circulation. Should the forces of disease predominate, critical occlusions may develop at any level below the midabdominal aorta. The popliteal, anterior and posterior tibial, and peroneal arteries are most commonly involved.

In addition to the primary closure caused by the progressive extension of atheroma into the lumen of the vessel, secondary causes of closure are the formation of thrombi over ulcerated plaques, and hemorrhage into the wall of the vessel. Finally, Burton has pointed out that an inherent tension exists in the wall of the vessel which represents both "active tension" or "vasomotor tone" due to active contraction of elements in the wall of the vessel, and "elastic tension" due to distension of the wall beyond its resting dimensions By application of the law of LaPlace he has shown that if the pressure within the lumen should fall below a "critical closing pressure," then the tension in the wall will, of itself, result in closure of the vessel. This may happen in arteries smaller than the aorta.

A rich supply of preformed intra-arterial anastomoses represents the primary defense of the body. When a focal closure occurs, these anastomotic channels open and carry the blood around the occlusion Insofar as possible, they return below the obstruction to the larger vessel It should be borne in mind that in accordance with Poiseuille's law, pressure and flow vary with the fourth power of the diameter of the vessel; halving the diameter will result in a drop in pressure or flow to one-sixteenth the initial value. The anastomoses, therefore, represent a limiting factor to blood flow, and may restrict it below the metabolic needs of muscle when actively contracting, thus producing intermittent claudication On the other hand, with the passage of time they may expand, thus more nearly equalling the original supply.

In addition to the hydrodynamic factors disposing toward closure, the amount of vascular tone must be considered. This provides another factor restricting the total effective diameter of the vascular bed, thus increasing the peripheral resistance. Much of our therapy is directed along this avenue. Vasomotor tone is largely under the control of the sympathetic nerve fibers, and our efforts are most profitably directed towards decreasing or blocking the vasoconstrictor impulses, and towards augmenting the vasodilator effects. In this fashion, total blood flow through the limb may often be kept at a level sufficient to maintain the nutrition of the part.

The recent aggressive program of investigation has produced an impressive amount of clinical and experimental data. Although neither comprehensive theory nor critical experiment has yet been achieved, certain trends have become discernible. This may be considered as the direct result of the distinction between the aging process and clinical atherosclerosis. The aging process results in the replacement of contractile and elastic elements of the vessel wall by collagen, with fibrosis, ectasia, and elongation of the vessel. In no case, however, does the aging process result in obliteration of the lumen. The several theories that have been propounded to explain the development of the atheromatous lesion may be better understood by first considering certain observations on the clinical behavior of the disease. Direct experimental studies have been hampered by the lack of a suitable animal which, in natural habitat, develops a similar disease spontaneously.

Clinical Facts about Atherosclerosis. ***Age:*** Arteriosclerosis obliterans is itself a disease of the older age group. It is infrequent in patients under

the age of fifty. The atherosclerotic process, however, may appear at any age. Autopsies of a group of U. S. soldiers—average age twenty-two years—showed significant atheromatous deposits on the coronary arteries of forty per cent of the hearts studied. An occasional case of juvenile atherosclerosis, even of a three month old child in which this was the cause of death, or the rare patient who dies of another disease in his eighth decade with no evidence of any atheromatous involvement, underline the observation that although age is a rough index of atherosclerotic involvement, there is no direct and casual relationship.



FIGURE 6 Arteriosclerosis obliterans X-rays of foot showing definite evidence of arteriosclerosis of the posterior tibial artery with no change in the dorsalis pedis This illustrates the manner in which arteriosclerosis may involve isolated segments of the arterial tree anywhere in the body.

Systemic Disease: Acute and chronic infections have never been implicated, except that the aorta which has suffered syphilitic involvement is highly susceptible to atheromatous deposits at the site of the syphilitic inflammatory process. On the other hand, in nephrosis, myxedema, and familial xanthomatosis, a marked increase in atherosclerosis is common, and diabetics of both sexes are notoriously prone to early and severe atherosclerosis. There is a high degree of involvement in the hypertensive group, and conversely, patients with arteriosclerosis are prone to hypertensive disease.

Sex: During the child-bearing years women have considerably less atherosclerosis and atheromatosis than men of comparable age. As they pass through the menopause and into succeeding decades, women tend to approach men in the morbidity rate of the disease. Numerous correlations have been noted by clinical observation and experiment in man and animals, showing that one or another of the chemical concomitants of atherosclerosis varies directly or indirectly with the changes in the level of sex hormonal activity. Some years ago Lake, Pratt, and Wright studied

a group of department store workers and found that in the two groups under sixty years of age evidence of this condition was at least twice as common in the men. In a group over sixty years of age there was a higher incidence in both sexes, and the sex differential was much less marked.



FIGURE 7. Arteriosclerosis obliterans Scattered plaques of calcification along the course of the femoral artery in the thigh Although this involvement appears scattered the x-rays to not indicate the extent of intimal thickening nor the presence of thrombi which may produce occlusion of such a vessel at any time.

FIGURE 8. Arteriosclerosis obliterans An arteriographic study in which the femoral artery was obliterated in the midthigh but collateral branches carry the blood around the obstruction and back into the femoral artery just above the popliteal space.

Race and Heredity: An increased incidence of atherosclerosis can be traced through certain family groups in which it has acted as a mendelian dominant, but this is merely an increased likelihood of developing the disease, and may be a reflection of the secondary effects of some other metabolic or structural trait. Similarly, although it appears to be commoner among Jews and less common among Orientals, the contribution of economic and cultural factors has until now blocked any clear-cut

delineation of the importance of racial factors. It seems to occur more frequently in mesomorphs.

Diet: It is generally conceded that diet influences the formation of atherosclerosis. Wilens has shown that in the population coming to autopsy at Bellevue Hospital there was a significantly higher percentage of atherosclerosis in the obese than in the underweight members of the



FIGURE 9 Arteriosclerosis obliterans An arteriographic study illustrating a complication of arteriosclerosis obliterans, namely: A false aneurysm in the popliteal space produced by a split one-half inch long through a calcified plaque in the popliteal artery. This had been previously diagnosed as a tumor, the arteriogram clarifying the diagnosis The clot was removed, the slit carefully repaired and reinforced, and a previously condemned leg was restored to normal

group. When different ethnic groups are compared, there seems to be a correlation between the amount of fat and calories in the diet, and the degree of atherosclerosis. More significantly, when World War II occasioned food-rationing in Norway, and a reduction in total caloric intake, a striking drop of as much as two-thirds was observed in the mortality from circulatory disease, which continued until the diet was augmented. One must be guarded against drawing too comprehensive conclusions from such data as these; there were other changes in Norway under the occupation. For example, the use of tobacco was very greatly reduced, and some

have drawn similar conclusions from this. In experiments on human volunteers it has been shown that the total cholesterol and various partitions thereof can be influenced by alteration of the diet, and specifically, that if patients be maintained on a low fat, low calorie diet, their blood lipids will be lowered. Finally, it is of interest that prolonged and generous imbibition of alcohol seems in some way to protect against the formation of atheromata.

Theories: Although individual workers and groups tend to focus their attention on one particular aspect of the problem, and thus no one factor has been shown to be responsible for the development of atherosclerotic lesions, the current belief is that they must be explained in terms of the interaction of the blood vessels and the liquid flowing through them, with attention being paid to both the metabolic and the hemodynamic forces that are brought to bear.

Blood Lipids: The fatty content of the lesions and the observation that the metabolic diseases of hypercholesterolemia were associated with widespread and severe atherosclerosis first focused attention on the question of fat metabolism. Further stimulus was given when an atherosclerotic lesion was produced, first in the rabbit and later in the chick, by diets high in cholesterol. However, the early enthusiasm was soon dampened by the finding of high blood cholesterol levels in patients who did not develop the atherosclerosis, and, conversely, by the development of lesions in patients with apparently normal blood cholesterol levels.

It is known that the cholesterol is held in solution as lipoprotein, and in recent years attempts have been made to characterize various fractions of the lipoprotein moiety. Gofman has used physical technics, and has reported that by analytic ultracentrifugation the lipoproteins can be divided into several subgroups. He feels that certain "giant molecules" are sharply increased in patients known to have coronary artery disease, and therefore atherosclerosis. He reported that in age and sex distribution these "giant molecules" attained their highest concentration in the groups most likely to develop atherosclerosis. Furthermore, he has published figures showing that if patients maintain a low-fat, low-calorie diet, then the level of these "atherogenic" molecules will be depressed

Barr and his group have studied the lipoproteins by the use of Cohen's method X, which effects a chemical separation into groups referred to as alpha and beta lipoproteins. The alpha lipoprotein molecules contain almost three times as much phospholipid as do the beta lipoprotein, but it is the blood level of this larger, less stable beta lipoprotein which seems to parallel the degree of atherosclerotic activity. Furthermore, the ratio of alpha and beta lipoprotein can be controlled quite readily by administration of sex hormones over long periods of time.

In the above and in other studies many workers feel that it has been possible to define or characterize the particular fraction of the lipoprotein moiety which is involved in the production of atherosclerosis. Ahrens, Kunkel, and others have studied the cholesterol-phospholipid relationship, and in similar fashion find that an increase in the percentage of cholesterol predisposes to atherosclerotic deposition.

Finally, studies of the diet have shown that the body is capable of synthesizing large amounts of cholesterol from either animal or vegetable fat, and that if total cholesterol or any of the fractions are to be altered, it can only be accomplished through a diet markedly restricted in both fat and total calories.

Physical Factors: The localization of atherosclerotic plaques to rather characteristic and well-limited areas has called attention to the physical factors which are involved. It has long been known that areas of endothelial thickening predispose to the lesions, and areas of stress and high pressure have also been implicated. Recently certain fundamental laws of hydraulics have been applied, particularly as stated in the LaPlace equation, which gives an estimate of the amount of tension occurring in the vessel wall. It can be shown that the intraluminal tension is increased in areas of dilatation, such as the antrumlike widening of the femoral artery before the branching of the profunda femoris, and these are, indeed, likely spots for plaque formation. Application of these laws will contribute to the explanation of the localization to one side of an artery, under certain conditions.

The Filtration Theory: Most of the above theories may be integrated by the so-called "filtration" concept which holds that the contents of the plasma are perpetually being filtered through the walls of the blood vessels, perhaps undergoing metabolic activity en route. At any rate, either an increase in concentration of certain materials, or a metabolically or physically induced defect in the manner of handling the material *at the particular site* results in the loss of ability to remove all the material which was being filtered. This results in the accumulation of lipids in the vessel wall, and then sets in motion the process of injury, repair, and continued accumulation, which results in the atherosclerotic plaque.

Clinical Picture of Arteriosclerosis Obliterans: The patient with arteriosclerosis obliterans is most often a male, over fifty. His first complaint is usually of pain in the affected limb, most frequently with intermittent claudication on walking, and although the onset may have been gradual, many patients are very specific in describing the moment at which the pain was first experienced. They also commonly experience a feeling of coolness in one or both feet, and sometimes are aware of changes in the color of the feet. The severity and ease of elicitation of the pain offer an estimate of the severity of the arterial impairment. Pain persisting when at rest indicates a very serious degree of ischemia, and exquisite pain with every step suggests the presence of an ulcer or a pregangrenous state. In older age groups, the percentage of females increases, particularly in patients with diabetes.

Intermittent Claudication: This is the classical pain of arteriosclerosis obliterans. It is usually described as a cramping, aching, or stinging pain, or a feeling of fatigue or tightness which appears after walking a distance which is generally fairly well standardized for a given patient at any given time. It most commonly presents itself in the calf muscles or in the dorsum of the foot. It may be perceived in the thigh, and in high occlusion may radiate into the buttock. It is characteristically relieved by rest, after

which the patient can once more walk about the same distance The "claudication distance" is shortened by cold weather or by walking up an ascending grade.

This pain occurs when the impairment to the circulation is such that the blood supply to the involved muscle groups is adequate for the resting state, but not sufficient to meet the demands of exercise. At such times the metabolic activity may be increased thirty fold above the resting state. Normal physiologic mechanisms increase the blood supply by increased cardiac output and by local vasodilatation, and also increase the amount of oxygen extracted from each unit of blood. In arteriosclerosis obliterans, occlusion of a considerable proportion of the available vasculature rigidly limits the available blood flow, and when this limit is exceeded by the metabolic demand, an unknown mechanism elicits the pain of intermittent claudication. The pain is believed due to the accumulation of acid metabolites, to neural ischemia, to some chemical imbalance, or to some combination of these factors. Regardless of the exact mechanism, there is universal agreement that the pain is elicited when blood flow is inadequate to meet the needs of a contracting muscle.

Color Changes: Pallor of the foot on elevation and rubor on dependency are often of much concern to the patient, and of great use to the physician in evaluating the circulation of the limb. The color of the skin is largely determined by the state of the blood in the subpapillary venous plexus, and this, in turn, is largely mediated by the circulatory status of the arterioles. With progressive obliteration of the arteries, due to the intimal proliferation of the atheromata and thromboses, there is a progressive reduction in the pressure available to the blood as it enters the capillaries. In the face of the loss of pressure, gravitational action becomes more and more important. Therefore, when the affected limb is elevated, blood drains out through the venous return channels, but the blood which would ordinarily replace it is not able to overcome the force of gravity, and the extremity is left pale and cool. When the leg is lowered, blood pools in the subpapillary plexus It no longer carries sufficient *vis a tergo* to pump it through the capillaries and into the venous return system. It therefore lingers in the capillary loops, giving up a disproportionately large amount of oxygen. The result is the accumulation of a large amount of "dark" blood, due again to the dominance of gravitational forces. Normal toes will change color very slightly with positional changes. In addition, this relative ischemia interferes with the nutrition of the smaller vessels, and their walls lose the normal muscular tone.

Trophic Changes: When the blood supply to an extremity has been impaired for any significant length of time, growth and repair of the extremity will mirror this insufficiency. Growth of nails is a function of blood flow, and similar evidence of inadequate nutrition will be seen in atrophy of the skin, loss of hair, and even muscular atrophy with reduction in the circumference of the extremity. Osteoporosis may occur, and may be due in part to disuse, although the degree of osteoporosis will be most marked at the area of the greatest ischemia. This may be so marked as to be confused with osteomyelitis by unskilled interpreters of x-rays.

Ulcers: A serious result of the impaired nutritional status is the formation of arteriosclerotic ulcers. They are an expression of the inability of the skin to maintain its integrity, and to repair even minor damage. The commonest sites are the toes, usually about the nail or at a joint, and the pressure areas of the heel. Ulcers may also be seen on the anterior tibial surface, although less commonly. They are usually small, and, if secondary infection is present, they may be moist. The base is shaggy and dirty, and the edges often undermined. Indolent infection of the adjoining tissues is common, and the ulcerated area may be extremely tender, so that even the pressure of the bedclothes causes agony. Diabetic patients frequently have little pain due to the peripheral neuritis which may interfere with sensation. The same ischemia which contributes to the establishment of the ulcer tends to perpetuate it, as the processes of defense against infection and repair are limited by the blood supply.

Gangrene: Gangrene usually appears at the tip of a digit in which the circulation is impaired, and may spread proximally to include the entire toe, and, in severe cases, even the foot or lower leg. If unmolested, mummification with autoamputation may ensue ("dry gangrene"), or, if secondary infection supervenes, the "wet" type of gangrene will occur.

Temperature: These patients frequently complain that the foot or toe is cold, and that it is difficult to warm it. Studies of the surface temperature confirm this observation and also show a lowered skin temperature in many other patients who do not appear to be conscious of the lowered temperature. This finding is commonly associated with arterial occlusion unless the collateral vessels have taken over the burden of the circulation satisfactorily. The normal skin temperature in a room of average temperature 20° to 25° C. (68° to 74° F.) should average from 29.5° to 34° C. (85° to 93° F.), but many extremities with advanced arteriosclerosis persistently maintain temperatures as low as the level of room temperature. It must be remembered that low surface temperatures may also be found in the presence of vasospasm, either temporary or fairly permanent. This is common with females.

The color changes described above are altered if the temperature of the limb is below 10° C. (50° F.) due to changes in the oxygen dissociation curve. At these temperatures the blood will not part with its oxygen, the minute vessels are damaged and dilated, and the skin becomes bright red in color even though the blood flow is small.

Suddenness of Onsets: The acute onset of an episode of pain may occur when, despite progressive narrowing of key vessels, the critical level of reduction of flow is suddenly attained by intraluminal thrombus about a protruding portion of a plaque, or intramural hemorrhage followed very rapidly by occlusion. In this situation, particularly if the patient is fibrillating, distinction from embolization may be extremely difficult. Fortunately the treatment is essentially the same.

Aneurysm Formation: Another possible complication is the development of aneurysm, particularly in the popliteal or common femoral areas. Rupture or thrombosis of such an aneurysm may occlude a major portion of the blood flow to the leg. In addition, emboli may break loose from a

mural thrombus in the aneurysm and descend to occlude the distal arteries of the leg.

Examination of the Patient with Arteriosclerosis Obliterans. ***General Examination:*** In the general examination of the patient two factors should be searched for diligently; first, evidence of vascular disease elsewhere in the body, such as arcus senilis, coronary heart disease, hypertension, or cerebral vascular disease; second, evidence of lung, heart, or blood defects which might affect the ability of the body to transport a maximum amount of oxygen through the blood to the limbs Chronic lung disease may decrease the arterial oxygen saturation; congestive heart failure will reduce the cardiac output. Infections elsewhere in the body will reduce the percentage of the cardiac output available to the limbs. Finally, disease states which may impair the body's metabolic efficiency, such as diabetes, or even predispose towards atheroma formation, such as hypercholesterolemia, should be sought for.

The Extremities: Examination of the extremities should be conducted in orderly fashion. As already discussed, the examination should include,

Pallor in elevation
Rubor in dependency
Skin temperature
Edema
Gangrene
Ulceration
Fungus
Hair growth
Nail growth
Skin quality
Atrophy of muscle groups
Palpation of key arteries—Femoral
Popliteal
Dorsalis pedis
Posterior tibial

The presence of varicose veins should be noted carefully. Varicosities complicate the picture because incompetence of the venous valves increases the back pressure against which the arterial pressure must pump This augments the arterial inadequacy by further decreasing the filtration pressure. Tissue edema increases the tendency toward infection The varicosities themselves may add considerably to the discomfort of the patient.

Simultaneously with the observations of color changes with the feet in various positions, notice should be taken of venous filling time. Following elevation of the feet above the heart level sufficiently long to produce collapse of the superficial veins, the feet are quickly dropped to a dependent position. The length of time required for the veins to refill is determined. Normal venous filling takes up to about thirty seconds and the degree of arterial impairment may be estimated in terms of prolongation beyond this time. One warning must be given; the observer must be most careful to be certain that the filling takes place from below upwards (from the distal portion centrally) and not from above downwards, since the

latter action may be the result of incompetent venous valves permitting back flow.

Special Technics of Examination: In addition to careful history taking and observation based on the above outline, which will frequently be sufficient to establish the diagnosis, there are additional tests which will help to confirm this impression and to establish the amount of damage involving the circulatory tree.

Oscillometric readings are very useful in determining the patency of major vessels and the level of their occlusion. After a study of many thousands of these readings we feel that there has been a tendency in some quarters to overinterpret and to draw unwarranted conclusions from such studies. It appears unwarranted to attempt a definition of the type of sclerosis involved, but if we confine our interpretation to the level of occlusion, which is what the machine actually determines, valuable information can be obtained.

By increasing air pressure in the cuff to the point where no pulsation is noted and then lowering it 10 mg. of Hg at a time, recording the degrees of pulsation at each level, it is possible to plot a curve. The shape of such curves has been the cause of much study, but for practical purposes the important point is that of maximum pulsation and the amount of pulsation at that point should be noted. When the major vessels are functioning, pulsation will be noted. When they are not functioning, no pulsation will be seen. This is much more reliable than palpation since such factors of error as pulsations of the examiner's fingers and aberrant locations of the vessels are eliminated. Furthermore by moving the instrument up the calf or thigh the level of closure can be ascertained where palpation is obviously impossible. Readings should be made in a room where the patient is warm, since chilling may produce spasm of the vessels and diminished pulsation. The average normal readings at various levels are as follows:

Leg		*Arm*	
Arch of foot . . .	¼ to ½ degree	Hand	½ to 2 degrees
Above ankle . . .	1 to 3 degrees	Above wrist	1 to 3 degrees
Below knee	2 to 5 degrees	Above elbow	2 to 8 degrees
Above knee	2 to 10 degrees		

Oscillometric readings do not give us information about the collateral circulation which may overtake the burden of the major vessels quite satisfactorily when the latter are occluded. This we must determine by other methods outlined below.

Surface Temperature Studies: It is often quite necessary to use a thermocouple to determine by the skin temperature that the circulation is impaired. While normal extremities may be either cool or warm, a marked difference between the two sides is very significant when they have been exposed to the same environmental stimuli for the preceding hour or more. This difference even when only a fraction of a degree centigrade can be readily recognized by the examiner's hands. The dorsal surface of the examiner's fingers is especially sensitive for this test. In arteriosclerosis the cooler extremity has the most markedly impaired circulation. If one

wishes to record the difference and actual levels, a thermocouple or radiant heat measuring instrument should be used. The readings should always be interpreted, taking into consideration the room temperature, and no readings should be considered as indicative until repeated readings taken in a given environment fail to show fluctuations of more than one degree Centigrade.

Reflex Vasodilation Tests: Numerous tests have been described to produce reflex vasodilation, and hence, in a sense, measure the potential arterial blood supply available at a given time. They are based on the observation that if one part of the body is markedly warmed, vasodilation will take place in other parts, especially of the extremities. If this is done in normals the temperature of the part being tested can be elevated to 32.9° to 33.9° C. (91° to 93° F.). If the circulation to a given extremity is impaired markedly there may be no rise above room temperature. All degrees of impairment may be noted between these extremes.

Landis and Gibbons suggested immersing the uninvolved pair of extremities in hot water 43.3° to 44.3° C. (110° to 112° F.) for twenty to forty minutes. Maddock suggested wrapping the patient in blankets and hot water bottles. The use of a heat pad on the abdomen or wrapping both arms in a heat pad is satisfactory. Other methods, such as blocking of the properly selected nerves (e. g., posterior tibial nerve for the feet), spinal and general anesthesia, etc., have been used but are usually unnecessary except as a check on the simple methods in doubtful cases.

X-ray Flat Plates, especially by means of a soft tissue technic, are useful for determining the presence or absence of arteriosclerotic plaques along the course of the vessels under suspicion. They have in the past, however, been the source of great errors in interpretation. We cannot tell by the degree of sclerosis noted whether there is occlusion of the vessel or not. Vessels showing the most characteristic "pipe stem" calcification have proven on autopsy to be patent throughout, and, conversely, vessels showing only a few scattered plaques have been occluded high up in the limb if the plaques located there happened to produce a thrombus at that level. This point is not sufficiently well appreciated by the medical profession as yet.

Arteriography: Perhaps the greatest amount of information regarding the state of patency of the collateral as well as the main trunk arteries can be obtained by the use of a radiopaque substance directly injected into the arteries and x-rayed while in these vessels. The substances most widely used for this purpose are diodrast and thorotrast (thorium dioxide sol). For arteriograms from 15 to 20 cc. of the substance is used and we have knowledge of thousands of such injections with complications of a minor nature only in the case of thorotrast. There have been a few deaths reported from diodrast.

The technic requires close cooperation between the operator and the roentgenologist. Certain operators cut down on the artery (brachial or femoral) to insert the needle but we have not found this necessary, merely locating the artery by palpation and inserting the needle therein. This is occasionally difficult, especially in obese patients. A size 16 to 18 gauge

needle is used and after about 8 to 10 cc. of the diodrast has been injected the x-ray operator begins to take pictures, the extremity having been placed properly before the procedure was started. Serial plates will show the opaque substance in the main trunks, collateral vessels, arterials, venules, and veins. Points of blockage and collateral repair are clearly seen. Effects of treatment can be followed by a recheck months later. It should be noted that the point of apparent blockage may in fact be a point of spasm which extends up the vessel walls well above the level of the organic occlusion. We have seen this released down to the latter level in the legs following a spinal anesthesia. No evidence of serious leakage of the arteries has ever occurred in our experience.

This must be classed as a useful procedure especially where detailed studies are being made and where proper facilities and well trained workers are available. *It is not necessary for routine study in most cases of arteriosclerosis.*

Numerous other substances have been used, such as skiodan and uroselectan, but thorotrast is less painful, less apt to produce a slough, and generally is more satisfactory.

Histamine Flare Tests: Histamine flare tests have been advocated as a test of the circulation. Following the injection of histamine intradermally a flare normally develops extending 1 to 2 cm. from the site of injection. If the circulation is impaired this flare does not develop satisfactorily. It appears to us to be a test depending on the superficial rather than the deep circulation and the factor of the state of the lymphatic vessels seems to play a part. If a series of injections are made up a leg, a rough idea of the level of impaired circulation may be gained by observation of the reactions. Perlow feels that the temperature to which the wheal rises is more important than its size—normal wheals reaching a temperature of 33.6° to 34.6° C. (92.5° to 94.5° F.) for the upper extremities, 32° C. (89.6° F.) for the feet.

Measured Work Tests: If a patient is made to walk a certain distance or up a flight of stairs at a fixed pace and observed for the onset of claudication pains and the point beyond which he cannot proceed, valuable information will be gained for comparison with future studies after treatment.

Similar observations, perhaps more accurate, can be gained by the use of various types of ergometers in which the patient lifts a weight by means of a walking motion such as we use, or where the patient is forced to contract his muscles by faradic electrical stimulation until the muscle can no longer function.

Treatment. General Principles: Satisfactory therapy is available for most patients with arteriosclerosis obliterans if they are seen before the stage of marked gangrene. Despite the absence of any specific therapy dealing effectively with the causative lesions, careful study of the disease process and the pathologic physiology involved have made it possible to develop a plan of treatment which will usually enable the patient to establish an adequate collateral circulation. It must be borne in mind that this therapy involves the development of collateral channels of circulation

and must be accomplished in terms of weeks or months, in contrast to the rapidity with which certain of the infectious diseases and some types of congestive heart failure respond to specific therapeutic agents. Both patient and physician must be prepared to accept this long range approach.

The technic of treatment is aimed at increasing the blood flow through the limb or decreasing its metabolic need. In some cases measures are available for reversing or reducing the progress of the disease, and the general efficiency of the entire bodily economy must also be considered. *Finally*, there must be considered the long range problem of teaching the patient to live in such a fashion that future local insults, such as trauma or frostbite, may be avoided, and that he may live most comfortably with the residuum of his illness.

Measures Aimed at Increasing Blood Flow. *Reflex Heat.* Although the application of local heat directly to the legs must be scrupulously avoided, considerable vasodilation may be accomplished by applying a *hot water bottle* or an *electric heating pad* to the lower abdomen. This is in essence a modification of the Landis test, and accomplishes a reflex neurogenic vasodilation. Inasmuch as this is mediated through sympathetic pathways, it has the additional advantage of counteracting directly vasospastic efferent impulses. *Diathermy* or *short wave* can be applied to the lumbosacral area or across the hips with similar effects. It should not be applied directly to legs with impaired circulation. This heat should be applied intermittently, one hour three times daily is usually adequate. In similar fashion, with added direct dilatation, a *one hour tub bath*, in water between 35° and 37.8° C. (95° and 100° F.) will often encourage the opening of the collaterals.

Drugs: Two families of drugs are generally believed to be useful. One group includes the sympathetic blocking agents, and of these *priscoline* has been most widely used. The dose should be increased over several days, until 25 mg. by mouth four times daily has been reached. Many patients have been continued on this drug for several years, and at the end of that time still appear to be helped by it. Recent reports also suggest that priscoline and *reflex heat* complement each other's activity. Other drugs of this group include *roniacol* and *ilidar*. These drugs should not be used if the patient has a tendency toward peptic ulcers, which may be reactivated. In addition, some patients cannot take them because of general reactions including vertigo, nausea, tingling of the skin, and chilly sensations. Another useful drug is *alcohol*, which has a powerful vasodilating effect on peripheral arteries, a beneficial effect on mood, and aids in the control of pain. In our laboratory we have shown that a temperature rise of as high as 12° F. may follow the ingestion of 60 or 90 cc. (2 or 3 ounces) of whiskey. In patients with impending or actual gangrene, as much as 60 cc. of whiskey may be given every three or four hours, until the acute situation has been resolved. Many patients continue to take 60 cc. (2 ounces) of whiskey two or three times daily for long periods of time. *Gin*, *rum*, or *wine* may be substituted. There is no basis for the belief that any particular kind of alcoholic beverage is superior in this respect, nor for the old idea that rye whiskey contains ergot and should be avoided

It should be pointed out that there is some doubt that the use of generalized vasodilators such as those we have mentioned increase the blood flow in the diseased extremities. Actually the rest of the vascular system may dilate more easily, and without an increase in blood volume the affected limb may, at least in some cases, be further deprived.

Removal of Vasoconstrictors: Any other medications which the patient is taking for unrelated conditions must be scrutinized, and any obvious vasoconstrictors, such as ergot, removed from the regimen. Adrenalin should be avoided even for dental work. Most important of all, *the use of tobacco in any form is absolutely interdicted.* The effect of nicotine is more marked on the smaller than on the larger vessels, and it is precisely these smaller vessels which are so important in the development of collateral circulation. Furthermore, the narrowing of a proximal segment lowers the head of pressure distally, and the stasis, or slowing of blood, may then predispose to further thrombus formation, resulting in complete occlusion of a formerly patent collateral trunk. We therefore insist that all our patients abstain from the use of tobacco in any form.

Exercise: Physiologically, exercise represents one of the most potent stimuli to vasodilation. In less severe cases without ulceration, repeated walking to the point of pain is encouraged, both because of the actual stimulation to the circulation, and because of the "lift" it gives the patient's spirits when he is told that walking is actually good for him However, he is instructed not to continue once pain has occurred without a pause to permit the metabolic demands to be met. During the early stages of healing of arteriosclerotic ulcers and gangrene, weight bearing is discouraged, because of the damage done to local reparative measures However, in no case should patients be confined completely to bed for long periods of time, as they are then liable to develop a secondary atrophy of disuse with local vasospasm.

Position: It has been found that patients with aterial insufficiency are most comfortable when lying with their legs lower than their heart. This may be accomplished by placing wooden blocks under the legs of the head of the bed, so that they are elevated 15 to 20 cm. (6 to 8 inches) above the floor. It is estimated that an increased blood flow to the lower extremities of as much as fifteen per [illegible] measure. It is an important adjur [illegible] rterio- sclerosis obliterans has been made, the patient should [illegible] ged to continue this measure at home indefinitely.

Oscillating Bed. Even more effective than the above is the use of the Sanders oscillating bed. This bed slowly tips up and down, see-saw fashion, on the long axis, so that the patient's legs are alternately raised and lowered. The bed is adjusted so that at the end of the up-cycle the toes have just developed obvious pallor, and that the down-cycle is terminated at the time the toes become definitely ruboric. The entire cycle should take about two minutes, with the feet rising about 15 cm. (6 inches) above horizontal, and descending 30 to 37.5 cm. (12 to 15 inches).

Relief from Pain: Pain from ischemic tissues may cause vasospasm which in turn causes more ischemia, resulting in more pain, and so on. It is of paramount importance that this vicious cycle be terminated. The patient

should be started on *aspirin*, and this, together with the whiskey, will frequently relieve the pain. If not, it is our practice to allow the use of *demerol* hypodermically in doses of 50 or 100 mg., or comparable doses of *codeine*. Usually, within a few days the pain will have subsided, except in far advanced cases which frequently require surgical intervention

Measures Aimed at Decreasing Metabolic Need. *Careful and Conservative Control of Any Infection:* This is a cornerstone of any therapeutic program. Any established areas of suppuration must be drained, and dead tissue debrided, with a minimum of trauma to adjacent tissues which, in contrast to the more usual type of surgery, are themselves in a borderline condition. *Antibiotics*, both local and systemic, are of help in eradicating cellulitis, and *foot soaks* are an important adjunct. The entire foot should be soaked for one half hour in the morning in a dilute (1:10,000) solution of *potassium permanganate*, and in the evening in *normal saline*. These soaks should be at a temperature of 35° to 38° C. (95° to 100° F.). This serves the purpose of loosening and washing away some of the crusted debris, allowing free drainage, and delineating the viable from the necrotic tissue. It has the further merit of bringing under control the dermatophytoses, which represent another common type of infection. After the soaks have been terminated, one of the fungicidal powders should be used once a day, for an indefinite period.

Local Measures: After suppurative areas have been drained and debrided, there follows a protracted period in which the collateral circulation is improving, and the ulcer is slowly granulating. In addition to the soaks described above, we have empirically included the application of *aureomycin ointment*, three per cent to the ulcer surface for several hours once a day. The ulcer should be examined frequently and the dead tissue removed once or twice a week, at a time of day when the tissues are still soft from recent soaking. Once infection has been controlled, the area should be kept dry, and exposed to air between treatments. This appears to give optimal healing.

Heat: It must be noted here again that excessive application of local heat will produce an increase in oxygen utilization which far outweighs any minor degree of local vasodilation which may be accomplished. In most cases good results are obtained by nothing more than the conventional number of blankets, or, when the patient complains of cold feet, the use of light-weight woolen bed socks. When a more aggressive approach is desired, a thermostatically controlled *heat cradle* may be used, providing great care be exercised to prevent local burns. In no case should the temperature inside the cradle exceed 35.5° C. (96° F.), and often a temperature of about 33° to 35° C. (92° to 95° F.) is satisfactory. Under no circumstances should the use of heat lamps, diathermy, or short wave therapy be considered. One of the authors (I.S.W.) has personally seen over seventy cases in which severe ulceration or gangrene has been precipitated by measures producing excessive heat. The above should not be considered in any way arguing against the production of *reflex* vasodilation by the warming of the abdomen or the upper extremities. The use of reflex heat provides one of our most effective stimuli to reflex vasodilation.

Measures Aimed at Reversing the Course of the Disease: Until more studies, particularly those involving long-term follow-ups of matched control and experimental groups of patients, have been completed, no definite statements can be made, except that those systemic diseases which predispose to atherosclerosis should be attacked with whatever therapeutic weapons are available at the time. If the patient's blood cholesterol is high, or he is obese, he should be placed on a low-fat, low-calorie diet for at least three months. At the end of that time if there has been a significant decrease in his blood cholesterol level, he may then be advised to continue on the diet. Inasmuch as thrombosis plays a significant role in the development of the arterial obstruction, the use of long-term anticoagulant therapy may be considered. During the periods when multiple thromboses appear to be occurring, the indication for the use of cumarin or phenylindanedione derivatives to lower the prothrombin activity of the blood is more urgent.

General Measures in the Management of the Disease. *Orientation of the Patient:* It is our belief that in the long-term management of this disease, much can be accomplished by a program of patient education. First of all, the general biology of the disease is explained to him. Especially for patients in the less advanced stages it is emphasized that the prognosis can be good, and much can be done to correct erroneous and alarming ideas about "gangrene" and "hardening of the arteries." Reassurance is important and the patient is cautioned against impatience during the latent period before improvement is noted. We have found that the patients who understand more about the nature of the disease are usually willing to give up smoking, and make fewer demands upon the physician. He is cautioned against exposure to cold environment, and warned not to expose his feet to extremes of either heat or cold. The essentials of foot care are explained, including the necessity of avoiding trauma, and of preventing fungous infections by either *dilute permanganate soaks* or fungicidal powder such as *desenex* or *timofax*. Also they are advised to train themselves to walk at a slower pace, and thus in many cases to avoid claudication. Finally, all obese patient are urged to reduce.

Surgical Aspects of the Treatment of Arteriosclerosis Obliterans. *Sympathectomy:* It is our opinion that lumbar sympathectomy is of limited and questionable value in the treatment of this condition. The majority of patients with arteriosclerosis obliterans will do at least as well, and often better on the program of therapy we have outlined. The effects of sympathectomy on intermittent claudication are minimal, and established gangrene cannot be helped. There are cases involving an occlusion of the vessels of a single toe, with much superimposed vasospasm, which may benefit, but such cases are rare. Cases in which benefit follows sympathectomy will usually be found in the hands of surgeons who, in addition to the operative therapy, carry out a program of supportive medical treatment very similar to our own. Sympathectomy should never be offered to the patient on the basis that it will enable him to continue to smoke. If he smokes it will be of no value.

Amputation: Discussion of the technic of amputation is beyond the scope of this presentation. However, certain medical aspects will be mentioned.

If the gangrene or infection which necessitates operation is extending, and the patient becomes toxic, operation should be performed forthwith, or after a period during which the foot is packed in ice. However, if the patient presents a more indolent process, a sufficient period of time should elapse to allow for maximal development of collateral circulation in the proximal tissues. The site of amputation must be carefully selected, in order to provide sufficient blood supply for the healing of the stump. Failure to observe this rule may lead to a series of amputations, with breakdown and infection of the stump, and continued loss of viable tissue

Clinical Division of Cases: Although the same general principles apply to all cases of the disease, mild and severe cases will require more or less intensive programs of therapy. The early or minimally involved patient presents himself to the physician with a story of intermittent claudication, generally after walking several blocks He is comfortable when at rest, and has never had any ulceration. On examination he displays moderate rubor in dependency and slight pallor in elevation of his feet The oscillometric readings of the feet and legs will be diminished, and pulses imperceptible in the dorsalis pedis and posterior tibial arteries. One or both feet may be involved. This type of patient generally responds well to a therapeutic regimen such as the following (General measures such as weight reduction are omitted):

1 Elevate the head of the bed 15 to 20 cm (6 to 8 inches) with blocks
2. Take a warm bath at 35° to 38° C. (95° to 100° F.) for one hour daily.
3. Priscoline 25 mg. by mouth after each meal and at bed time
4. Give up smoking, totally and forever.
5. If, after eight to twelve weeks, there has been no change in the degree of rubor, the oscillometric readings, or the claudication distance, it is advisable to add to the above the application of a heating pad to the abdomen for one hour several times daily.
6 This program to be carried out at home, for at least one year, with the patient leading an otherwise normal life

At the other end of the spectrum is the patient with actual or impending gangrene, or more usually with a well-established ulcerated area. These patients are more likely to have symptoms dating back for longer periods of time and may complain of rest pain. They are also more likely to have associated systemic disease. The program for the purely vascular aspects of therapy might be as follows:

1. Bed rest in oscillating bed. If able, he may walk to toilet once daily.
2. Heat pad to abdomen for one hour four times daily.
3 Foot soaks: $KMnO_4$ 1:10,000 in A M. Normal saline in P.M Each soak to be for one-half hour at tepid temperature
4. Priscoline 25 mg. by mouth after each meal and at bed time.
5. Alcohol, 30 to 60 cc. by mouth every four to six hours
6. Aspirin, 0 6 Gm. every four hours; demerol, 50 or 100 mg by hypo. every four hours when necessary for relief of pain. This becomes less necessary as improvement occurs. It has been noted that when therapy is instituted there may be a brief increase in the patient's complaints of pain This is believed to be due to return of nutrition to the pain-bearing neurones

7. Absolute and unequivocal abstinence from tobacco in any form.
8 Local debridement of ulcers and gangrenous areas, if present, every few days. Definitive surgical measures if indicated.

On the above regimen most ulcers will heal. Occasionally a patient may have an ulcer which is almost static, and although it will not heal, it does not appear sufficiently severe to justify amputation, particularly at the high level that would be required. We have sometimes agreed to allow these patients to return to their homes, if they would rent an oscillating bed, and continue with the therapeutic program. Some of these ulcers have healed after several months of treatment. We consider this far superior to amputation, which requires a period of rehabilitation considerably longer than is usually realized. In addition, there is the practical advantage of having preserved the extremity.

In closing, it should be noted that there has been renewed interest in surgical measures to restore continuity of blocked blood vessels by blood vessel graft. At the time of this writing, it is our opinion that sufficient experience has not as yet been amassed to merit widespread use of this procedure. It is felt, however, that in the hands of surgeons well trained in this field *further experience with this technic* is much to be desired.

REFERENCES

Pathogenesis

Ahrens, E H, Jr, and Kunkel, H G: J. Exper. Med. 90:409, 1949
Anitschow, N, and Chalatow, S S.: Zentralbl f. allg Path u path. Anat. 24 1, 1913
Barr, D. P.: The Pathogenesis of Atherosclerosis. Annual Lecture, Cleveland Academy of Medicine (May 18), 1951.
Barr, D P Josiah Macy, Jr, Conference on Hypertension and Arteriosclerosis, 1951
Barr, D P, and Russ E M Protein lipid relationships in diabetes mellitus, Tr A Am Physicians, 1951
Barr, D P · Circulation 8·641, 1953
Buerger, L The Circulatory Disturbances of the Extremities, W B Saunders Company, Philadelphia, 1924
Burton, Alan C Physiological Rev 34:619, 1954.
Cabot, R. C: J A M A 43 774, 1904
Collens, W S., and Wilensky, N. D: Am. J. Surg 34·71 (Oct) 1936.
Cowdrey, E V. (ed): Arteriosclerosis: A Survey of the Problem, The Macmillan Company, New York, 1933.
Craig, R L.: Disorders of the Circulatory System; A Symposium, The Macmillan Company, New York, 1952.
Dedichen, J, *et al* · Incidence of atherosclerotic disease during war years, Norway Tr 5th Conf. on Factors Regulating Blood Pressure, 1951, Josiah Macy, Jr, Foundation, New York
Duff, G. L, and McMillan, G C.: Am J. Med. 11:92, 1951.
Dufour, H: Bull et mém Soc. Méd. d hôp. de Paris 47:377 (March 16) 1931.
Enos, W. F., Holmes, R. H, and Beyer, J.: J.A.M A. 152·1090, 1953.
Fahr, T. H.: Verhandl. d. deutsch. path Gesellsch 15·234, 1912.
Fisher, J. W: Proc. A. Life Ins M. Dir. America 9:63, 1922-1923.
Gofman, J. W, *et al*: Circulation 2·161 (Aug) 1950.
Gofman, J. W., *et al*: Science 111:166 (Feb 17) 1950
Ignatowski, A: Virchows Arch. f. path. Anat 198·248, 1909
Katz, L. N, and Dauber, D. V.: J. Mt. Sinai Hosp 12·382 (May-June) 1945.

Joslin, E P: Ann. Clin. Med. 5·1061, 1926-1927
Lake, M., Pratt, G. H., and Wright, I S: J.A.M A. 119 696 (June 27) 1942
Leary, T.: New England J. Med. 205.231 (July 30) 1931.
Leary, T: Am Heart J 16·549 (Nov) 1938.
Ladd, A. T., Kellner, A, and Correll, J. W: Federation Proc 8 360 (March) 1949
Ludden, J. B, Bruger, M, and Wright, I. S · Arch Path. 33·58 (Jan) 1942
Marchand, F.: Verhandl. D. Kong. F. inn Med 21·23, 1904
Moritz, A R, and Oldt, M R: Am. J. Path. 13·679 (Sept) 1937
Ophuls, W.: The Pathogenesis of Arteriosclerosis, in Cowdry, E V (ed) Arteriosclerosis, p 249, The Macmillan Company, New York, 1933
Perlow, S: Am Heart J. 11:605 (May) 1936
Romberg, E.: Lehrbuch der Krankheiten des Herzens und der Blutgefasse 3rd ed Stuttgart, F. Enke, 1921.
Roth, G. M: Lactic acid in venous blood of ischemic extremities, Master's thesis filed at University of Minnesota, pp 1-64, June, 1936
Ruffer, M A.· Studies in the Paleopathology of Egypt, University of Chicago Press, Chicago, 1921.
Sherman, H. C: Chemistry of Food and Nutrition, The Macmillan Company, New York, 1926
Spain, D. M., Bradess, V. A., and Huss, G. Ann Int Med 38 254, 1953
Steinbiss, W: Virchows Arch f. path Anat 212 152, 1913
Steiner, A, and Kendall, F. E. Arch Path 42 433 (Oct.) 1946
Steiner, A. Kendall, F. E, and Bevans, M. Am. Heart J 38 34 (July) 1949
Symposium on Atherosclerosis. National Academy of Sciences, National Research Council, Washington, D. C.
Thomas, W. A.: J.A.M.A. 88 1559, 1927
Vanderveer, H. L.· Arch. Path. 12 941 (Dec) 1931
Wilens, S L.: Arch Int. Med, 79 129, 1947
Willis, G C: Canad M A. J. 70·1, 1954
Winternitz, M. C, Thomas, R. M., and LeCompte, P M The Biology of Arteriosclerosis, Charles C Thomas, Publisher, Springfield, Ill, 1938

Treatment

Allen, A W: Ann. Surg 92·931 (Nov) 1930.
Allen, E V, and MacLean, A R. Proc Staff Meet, Mayo Clinic 10 216 (April 3) 1935
Allen, E V., and McKechnie, R E, Jr, J Lab & Clin Med 22.1260 (Sept.) 1937
Allen, E. V. Circulation 5 98, 1952.
Barker, N W.· Proc. Staff Meet, Mayo Clinic 8 284 (May 10) 1933
Buerger, L: The Circulatory Disturbances of the Extremities, W B Saunders Company, Philadelphia, 1924
Denk, W.: Munchen med. Wchnschr. 81.437 (March 23) 1934
DeTakáts, G.: J A M A. 106:1003 (March 21) 1936.
Ginsberg, N · Am J. M. Sc. 154:328 (Sept.) 1917
Grimson, K. S, Hendrix, J. P., and Reardon, M J: J.A M A. 139.154 (Jan 15) 1949.
Keys, A., Science 112.79 (July 21) 1950.
Koga, G: Deutsche Ztschr f Chir. 121 371, 1913.
Lampson, R S: J.A M A 104:1963 (June 1) 1935
Lichtenstein, L., and Sewall, S: J A M A 136.827 (March 20) 1948
Littauer, D, and Wright, I S · Am. Heart J 17.325 (March) 1939.
McGovern, T, McDevitt, E, and Wright I S · J Clin Investigation 15·11 (Jan) 1936.

Maddock, W G, and Coller, F. A.: Ann Surg. 98:70 (July) 1933
Pratt, G. H.: Surgical Management of Vascular Diseases, Lea & Febiger, Philadelphia, 1949
Roth, G. M.: Tobacco and the Cardiovascular System, Charles C Thomas, Publisher, Springfield, Ill, 1951.
Sanders, C. E: J A M A. 106:916 (March 14) 1936.
Starr, I, Jr.: Proc. Soc Exper. Biol & Med. 29.166 (Nov) 1931.
Wessler, S: New Eng. J. Med 249:233 (Aug 6) 1953
White, J. C.: The Autonomic Nervous System, The Macmillan Co, New York, 1935
Wright, I S: J A M A. 115:893 (Sept 14) 1940
Wright, I. S· New Eng. J Med 225:805 (Nov. 20) 1941.
Wright, I. S, and Moffat, D: J.A M A 103·318 (Aug. 4) 1934

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Raynaud's Syndrome and Acrocynosis

RAYNAUD'S SYNDROME

Definition: Raynaud's original descriptions of a syndrome producing symmetrical gangrene included case reports of several different diseases according to our present understanding. There is still a considerable degree of confusion in the minds of many physicians regarding the types of cases which should or should not be included in this category A review of the subject resulted in the recommendation of certain primary requirements for diagnosis as follows: (1) Gangrene or trophic changes limited in a large degree to the skin. These changes are not usually present until the late stages of the disease. (2) Symmetrical or bilateral involvement The syndrome may originate in a single digit, later involving others. (3) Absence of evidence of occlusive lesions of the arteries until late in the disease. (4) Intermittent attacks of changes in color of various local areas which usually precede the trophic changes by months or years. Additional secondary criteria are also of some value in this connection and will be discussed later.

Pathology and Pathological Physiology: Major pathological findings in Raynaud's disease are conspicuous by their relative infrequency. The early manifestations of the disease seem to be on a vasomotor bias without established demonstrable pathology in the nervous system. This statement is made after consideration of certain claims of pathological changes in the sympathetic ganglia and in the spinal cord. These claims have not yet been confirmed. Later, changes may occur in the local small arteries with a tendency towards occlusion. This appears to be secondary to the repeated episodes of constriction. Vessels larger than the digital vessels do not tend to become occluded. Examination of the capillaries of the nailfold reveals a characteristic picture in late cases. These vessels become markedly dilated especially the venous limb of the loop. The dilation gradually tends to extend including the arterial limb. The explanation for this dilation may rest in the repeated erythematous phases following the spastic phenomenon during which times the loops are filled with blood to the point of over stretching.

The gangrene is usually superficial and localized to small areas, such as the tips of the fingers or toes, nose, ears, cheeks, chin, etc.

It has been the subject of some debate as to whether this gangrene is due to a local circulatory fault or to a purely vasomotor phenomenon frequently repeated and of sufficient severity to produce anoxemia of the

tissues to the point of local death. We believe that both factors play a part, that the original attacks are due to the vasomotor phenomenon, and that these gradually produce damage to the local arteries, followed by ischemia and death of the cells. This only occurs in severe cases. Many individuals have a Raynaud's vasomotor phenomenon intermittently for years without progression to gangrene. This we classify as a pre-Raynaud's syndrome since it is not possible to predict which of these cases will show progression to the gangrenous stage.

Observation of the nailfold capillaries during the cycle of the attack presents a good picture of the local pathological physiology involved. In the first phase, that of waxy pallor, few capillaries are visible, filling of the loops is incomplete and they have a segmented, broken appearance due to the fact that the walls are invisible and the column of blood cells is interrupted and static. No blood is entering the capillaries from the arterioles which are in spasm. The surface temperature of the involved areas is low usually approximating room temperature. In certain instances intermittent leakage may occur from the arterioles and by retrograde flow from the venules. If this occurs the capillaries may become more easily visible, in fact even distended. This blood is relatively static also and as deoxygenation takes place the part assumes a cyanotic hue. There may be patches of cyanosis and rubor during this phase. With the cessation of the attack the arterioles open up, pouring blood rapidly in the capillaries and vessels which become markedly dilated with red oxygenated blood. Some areas may remain cyanotic for a time since the supplying arterioles may not open simultaneously in all areas. The surface temperature of the erythematous areas rises rapidly to above the average (30.5° to 33.9° C.) (86° to 93° F.) during this stage.

Since scleroderma of the affected parts is so common a complication of the Raynaud's syndrome, a discussion of the pathology of this condition must be included.

In the involved areas the skin becomes tightly stretched, and the malpighian layer is atrophied. The deeper layers become fibrosed. Histologic examination shows hypertrophy of the collagen and stratum granulosum. This fibrosis extends into the subcutaneous layers, the muscles, and may bind the skin to bones which lie relatively near the surface.

Arteries such as the digital vessels are surrounded by fibrous tissues. Their channels are narrowed by intimal thickening and the external pressure resulting from the fibrosis. Pigmentation of the skin occurs at this time. Marked bony changes of several varieties may take place. Arterial changes may be of either atrophic or hypertrophic type. These changes combined with the fibrotic changes of the soft tissues not uncommonly result in ankylosis of the joint usually in a somewhat flexed position. Atrophy of the digital terminal phalanges is a common finding. This begins at the tip and gradually destroys the entire phalanx.

It should be noted that this process may invoke the entire surface of the body and also the internal organs such as the larynx, esophagus, heart, lungs, kidneys, and bladder. The most commonly affected areas in our experience are the fingers (sclerodactylia), hands, arms, toes, nose, cheeks,

Raynaud's syndrome showing extreme pallor and moderate cyanosis associated with the vasospasm produced by exposure to cold

and ears. The more marked involvement the lower the skin temperature. In advanced cases it approximates the environmental temperature level.

Examination of the capillaries in this condition shows them to be scattered, seen with difficulty, and constricted, with an occasional dilated one to be found. Stretching of a finger obliterates them with paling of the skin. Relaxation of the finger brings more into action as the pressure is released.

Etiology: The fundamental etiological factor in the production of the Raynaud's syndrome in the sense of a specific agent is not known. It is not even known whether it is on a bacterial, allergic, hormonal, or on some entirely different basis.

We do, however, know that certain stimuli are capable of initiating individual attacks. The most important of these factors is probably

Cold: If an individual with this syndrome is exposed to cold to a sufficient degree spasm of the affected areas takes place and this is not relieved until the environmental conditions are changed with an increase in the temperature level. Different patients respond quite differently to this stimulus. With some the temperature level must be quite low i.e., 4.5° to 7.3° C. (40° to 45° F.), with others who are more sensitive to cold the attack can be precipitated by a drop to much higher levels, i.e., 18.3° to 21.1° C. (65° to 70° F.). This is not infrequently seen during swimming with the water at that temperature. Chilling of the body usually induces spasm of the affected areas at higher levels of temperature than if the body is kept warm. In the other hand, as Lewis has pointed out, cold stimulation applied to the base of a finger may produce a typical attack of vasospasm limited to that area.

The result of this reaction to cold is that the symptoms are usually much more pronounced in winter than in summer months, and in the north than in the south. Certain advanced, highly sensitized cases continue to have their spasms under remarkably warm climatic conditions.

It should be noted that exposure to extremely cold 4.1° to 2.9° C. (25° to 30° F.) water may fail to produce the spasm. If the skin is sufficiently cold the blood will not give up its oxygen, the minute vessels are damaged, become dilated, and the skin becomes bright red.

It has been demonstrated that some patients with chryoglobulins in their blood may develop Raynaud's syndrome following chilling and this may be the explanation for the syndrome in those patients. Tests for chryoglobulins in numerous patients with Raynaud's syndrome, however, failed to reveal their presence except in very rare cases.

Emotion: Emotion is a factor of great importance in the production of attacks. Anger, fear, and excitement may all be capable of producing attacks in certain individuals. In some patients these factors may accentuate the effects of cold, in others the attacks may be produced by emotional stimuli alone in a warm room.

Repeated Vibration or Percussion Stimuli: Certain individuals who use vibrating tools such as pneumatic drills, rivet hammers, etc., may develop a traumatic, vasospastic phenomenon comparable to the Raynaud's syndrome. The reaction may take place during the action of the

machine especially in a cool environment or the individual may apparently be sensitized to cold by this repeated trauma. The cases thus far reported have been for the most part in individuals using the type of equipment above mentioned. We have reported similar syndromes following repeated slight trauma of a variety of types. In this group are included a typist, a concert pianist, a telephone operator, a handball coach, and others. The pianist was forced to give up his work for three years since each time he started to play the spasm occurred. The telephone operator developed the syndrome in one hand, the hand she used in "plugging in," in which procedure she frequently pinched her fingers between the plug and the switchboard. Superficial gangrene developed and she changed hands using the good hand. Within a few months this hand became similarly involved. These patients continue to have trouble if they remain in their occupations, unless they receive proper treatment, which will be discussed later.

Occlusive Arterial Disease: It should be recognized that in the early stages of occlusive arterial disease, *e. g.*, thromboangiitis obliterans, arteriosclerosis, etc., the Raynaud's syndrome may occur. This is probably due to the fact that with the lumena of the vessels narrowed and the walls damaged they are especially susceptible to irritation such as cold and slight spasm becomes a factor.

Arsenic: It has been suggested that this syndrome may develop as a result of the ingestion of arsenic either intentionally as in medication or unintentionally as on fruit skins. A check in our clinic of the presence of high arsenical urinary figures failed to produce any conclusive figures proving such a relationship. One might expect a high incidence of Raynaud's phenomena among treated luetic patients but this has not been noted.

Disturbed Calcium Metabolism: This has been claimed as the important factor[9] in the production of this syndrome but in our opinion the evidence so far presented is too inconclusive to prove this point.

Sex Hormones: The possible relationship to certain sex hormones should be mentioned. The Mayo Clinic has repeatedly published figures showing a sexual incidence of ninety-five per cent in females. This would appear to carry possible significance. In our clinic, however, the incidence in males appears to run nearer to thirty per cent thus giving the female ratio of seventy per cent. These may still be significant figures and work on the potential importance of sex needs further study.

Signs, Symptoms, and Course: From the viewpoint of the clinician it is helpful to recognize four stages of the Raynaud's syndrome. The reason for this is that any case may develop the signs and symptoms of any of these stages and may then either progress, remain in *status quo*, or tend toward improvement.

Pre-Raynaud's Syndrome (Early Raynaud's Syndrome): In this classification fall the mildest cases, many of which do not progress, merely showing a spastic response to cold throughout the patient's life span with no demonstrable pathology ever developing. Others do show progression, but so far as we know it is impossible at present to predict without con-

secutive observation which cases are benign and which seriously progressive. Certain patients have fewer symptoms after middle life

A typical attack may be as follows; the hands will be described as the affected part in this hypothetical case, other parts, if affected, react similarly.

Following exposure to stimulation, *e. g.*, cold, emotional upset, etc., the fingers begin to blanch turning a grayish color due to the deoxygenation of the remaining blood. The minute vessels frequently go into spasm forcing the blood out and producing a waxy color. If they remain patent filled with static blood, the spasm being confined to the arterials, the fingers become increasingly cyanotic. Cyanosis may also be produced by intermittent leakage from either the arterials or venules as explained under *pathological physiology*. If the finger is cut during this period no bleeding will occur from the waxy flesh and only slight oozing from the cyanotic areas, since both of these changes are manifestations of lack of blood flow. As these changes take place gradually increasing numbness is felt by the patient. In extreme cold this may progress to an aching type of pain but in our experience severe pain is rare at this stage. This phase usually remains as long as there is no change in stimulation, *e. g.*, so long as exposure to the requisite low temperature continues. These areas are especially susceptible to frostbite at this time.

With the removal of the stimulation, *e. g.*, cold, anger, the second phase, that of rubor begins. The affected area turns intensely red beginning at the proximal portion. This intense redness spreads like a wave distally completely enveloping the cyanotic or pale area. Some sections may remain patchy with alternating rubor and cyanosis for a brief time until all of the spastic vessels open. As this transformation takes place sensations of "pins and needles," tingling and even burning may be complained of. The finger temperature may become abnormally high, the vessels are overdilated. This phase may last a variable length of time, usually about twenty minutes, after which the fingers return gradually to their normal appearance, temperature, and feeling. The cycles may occur repeatedly on stimulation, sometimes many a day, at other times at much longer intervals. In general it appears that the more severe and more frequent the attacks the more apt the condition is to progress, but the exceptions to this rule are numerous enough to impress us with the probability that these are not the most important factors.

Trophic Changes: Among the first evidences of progress of this condition are early trophic changes at the tips of the fingers, toes, nose, or ears. These trophic areas are characterized by small dents and scales of brownish dry skin occasionally, but not always, preceded by tiny ulcers The ulcers may be very painful in proportion to their size but the trophic areas are not in themselves painful. If the condition progresses further larger ulcers involving the entire surface of the tip of the digit may occur. These are apt to be excruciatingly painful and are frequently moist and somewhat punched out. Most of them are, however, relatively superficial. As a result of these trophic changes and ulcerations the tips of the digits may be deformed and shortened.

Scleroderma (Sclerodactylia, Acrosclerosis): It should be made clear that there are cases of scleroderma which do not appear to be related to Raynaud's syndrome in any way. Perhaps we are not justified in including scleroderma as a stage of progression in the Raynaud syndrome. Yet there is a very high incidence of patients with this syndrome who develop sclerodactylia (scleroderma beginning in the finger tips) adding greatly to the seriousness of the symptomatology and complicating the therapeutic approach. The skin becomes increasingly hard, tense, shiny and pigmented. As explained under the heading of pathology the fibrosis responsible for this may become fixed to the bones and joints and produce a fibrotic ankylosis although the joint may not actually be involved at first. Later, hypertrophic and atrophic changes may be noted. The skin loses its natural color, the capillaries become increasing difficult to see, often resembling shadows without definite structure. The typical attacks of Raynaud's syndrome are more easily produced. Frequently the stage of rubor does not occur because of the pressure and tension of the skin and subcutaneous tissues.

The sclerodermatous changes may involve any portion of the extremities, trunk, or face, including internal organs. Pain is rarely a major factor if uncomplicated—stiffness and tightness being more commonly complained of. If, however, ulceration occurs there is often excruciating pain and tenderness. In addition, a syndrome known as calcinosis may further complicate the picture. Deposits of calcium may occur under any portion of the skin, not infrequently the extensor surfaces of the elbow, knee, ankle, or digital joints. If this calcified substance works its way out to the skin it usually produces considerable discomfort. At times it is necessary to remove some of this calcified material surgically to relieve the pain. It tends to recur at the same areas. The fingers gradually become fixed in a slightly flexed position. In advanced cases the hands may become useless.

When the face is involved the expression may be changed due to the tightness about the nose and mouth obliterating all wrinkles and making facial movement difficult. The neck may be stiffened. Numerous spider angiomata may appear, especially about the face. The genitalia in either sex may be involved to such an extent that intercourse becomes impossible. Whether actually a part of Raynaud's syndrome or not the two conditions occur so frequently with parallel courses in the same individual that one cannot adequately discuss one without considering the mutual relationship. Treatment for Raynaud's syndrome is quite different when scleroderma is present. This will be discussed later.

Gangrene: Frank, massive gangrene involving large portions of fingers, toes, or other areas is, as we see this syndrome today, a rare complication. It was reported more frequently in the older literature but careful analysis of these descriptions forces one to conclude that certain of those cases were, in reality, cases of thromboangiitis obliterans, others ergot poisoning, or frostbite, which may occur rather easily in patients with the Raynaud's syndrome while the vessels are in a state of spasm. If spasm of the arterial tree does occur with sufficient severity and frequency organic occlusion



Beginning erythema ten minutes after return to warm environment.

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as a result of clotting or changes in the vessel wall may take place This as stated above is in our experience rather rare in uncomplicated cases today.

Treatment: Protection: In the pre-Raynaud's and mild cases of Raynaud's syndrome the treatment should be largely protective The first step should be to avoid repeated producing stimuli, *e. g*, exposure to cold, extreme emotional crises, etc. If trauma is the precipitating cause the vocation or avocation should be discontinued or attacks will continue to occur.

The best way to protect patients from the cold is to have them remain in a warm dry climate during at least the winter months. If other factors play the major role, however, this will not control the syndrome.

If southern winters are not possible, every effort must be made to avoid extreme exposure. Winter sports, such as skating and skiing, are potentially harbingers of frostbites for these patients and should be avoided. The same holds for out of door winter work. When it is necessary for the patient to be out in cold weather, warm body clothing, warm socks, muffs, and gloves should be used. Shoes should be large enough for one or even two pairs of woolen socks without crowding. Small chemical heaters are valuable for use in the pockets or muffs to keep the hands warm. Electric heaters are of value in driving automobiles.

Treatment of Local Conditions: It is important not to suddenly overheat an area in spasm since unfortunate burns may occur before the circulation is adequate to carry off the excess heat and to handle the suddenly increased metabolic demands. Warming should be undertaken slowly.

Strong antiseptics such as the iodines, mercurials, silver salts, etc.; should be avoided since they may do more harm to the epithelization of an ulcer than to the bacteria present. Infection is rarely the important factor in these cases and mild antiseptics such as boric acid, normal saline, and azochloramide in triacetin 1.500 solution should be used if necessary. These ulcers heal best when dry. Hot soaks (temperature 36.7° to 37.8° C.—98° to 100° F.) using normal saline are recommended for one hour each day when infection is present. If wet dressings are used care must be exercised to keep them warm since chilling will tend to produce spasm of the vessels, preventing healing.

Vasodilating Drugs: Nitrites, Papaverine: The vasodilating drugs of this type do not appear to affect the course of either the Raynaud's or sclerodermatous syndrome. They may produce a relaxation of spasm but usually not if the producing factor is severe and still present. A mixture of nitrite compounds has been suggested for use prior to going out into the cold to prevent a spasm; this mixture includes rapidly and slowly acting nitrites (Vasodilator Compound, B. W. & Co.). Further studies must be made to determine its real value. Papaverine hydrochloride is of questionable value—warm water being more effectual as a reflex vasodilator. Tetraethylammonium bromide, while very temporarily a sympathetic nervous system block, has proved disappointing therapeutically.

Priscoline, roniacol, and ilidar are enjoying a vogue at present. They have been reported favorably from several clinics. We have used them with inconclusive results. Untoward effects include tingling of the scalp, lightheadedness, nausea, and sometimes necessitates discontinuing the drug.

Tobacco: The use of tobacco by patients suffering from the Raynaud's syndrome may be soundly contraindicated on the basis of its vasoconstricting tendencies and the probability that the more frequently constriction occurs in the small vessels the more apt permanent damage is to result. On the other hand, smoking does not appear to have the specific severe, aggravating effects in the Raynaud's syndrome that it does in thromboangiitis obliterans. Until further studies clarify this problem we advocate that all moderate and severe cases stop smoking. Thermocouple tests may determine which patients are particularly susceptible.

Surgery of Raynaud's Disease: It is the purpose of this presentation to discuss only the general aspects of surgery for Raynaud's syndrome and scleroderma and the results of the various methods used. Our conclusions will be based on the experience of our own and other active vascular clinics Certain statements may be made with relative conclusiveness at this time.

(*a*) No conclusions may be drawn as to the clinical result in any patient until that patient has been followed for at least one year after the operation. The literature has been full of reports of little value in which cases have been reported on a basis of one to six months postoperative follow-up. There is frequently a nonspecific improvement with encouraging surface temperature studies and lessened symptomatology for a few months. The results at the end of one year in the same patient may be entirely negative.

(*b*) Lumbar ganglionectomies are simpler technically and hence more satisfactory in general than cervical ganglionectomies. Unsatisfactory results are usually due to the fact that all of the necessary fibers have not been cut.

(*c*) In general the more advanced the condition the less satisfactory the results.

(*d*) Ganglionectomy does not benefit scleroderma.

(*e*) Parathyroidectomy has been recommended for scleroderma but in the few cases we have seen after one year there has been slight or no improvement. Several of these have reported a temporary improvement lasting for from three to six months.

(*f*) The only surgery holding forth a reasonable chance of success, ganglionectomy, is major surgery which should be attempted only by men who have special training in the field, and even then should not be entered into lightly from the viewpoint of the patient.

With these facts in mind it may be stated that in uncomplicated but progressively severe cases of the Raynaud's syndrome properly performed ganglionectomy offers a very good chance of relief from attacks and the comfort of warm extremities. Whatever the fundamental pathological physiological process may be it is probably not affected by this procedure

but the nerve impulses producing the attacks are blocked and the disagreeable symptoms and sequelae are held under control.

We do not recommend it in early cases since many of these do not progress, as stated above. If they do show evidence of progression, however, with increasingly severe symptoms it is wise not to wait too long until the disease has reached an advanced stage with sclerodermatous changes if good results are to be achieved. Since the condition progresses slowly there is usually a period of several years during which its course may be studied—only in the very rare "fulminating" cases is it necessary to make a hasty decision in this matter.

ACROCYANOSIS

There has been a tendency on the part of certain workers to classify acrocyanosis loosely with Raynaud's syndrome. While these syndromes have certain points in common such as blueness of the extremities and response to cold, there are many points of difference such as lack of the characteristic Raynaud attacks, presence of marked sweating, and the presence of edema in acrocyanosis, the difference in sex distribution, and other factors. In our opinion, therefore, precisive objective thought is hindered by attempting to group these two conditions under the same general heading. Rather their differences should be more completely studied.

Signs and Symptoms: The word "acrocyanosis" was first used by Crocq to describe a syndrome in which the hands and feet become a deep blue, especially in a cool environment The blueness gradually fades out at the wrists and ankles respectively. The volar surfaces are moist—freely sweating—the dorsal surfaces are dry. Pressure produces a white spot which slowly disappears. As pointed out by Stern this description requires amplification in several aspects as follows—the cyanosis is not permanent as Crocq originally thought, but disappears in all but the most extreme cases when the environment is sufficiently warm. Secondly, edema is often seen in extreme cases. [illegible] to [illegible] cor[illegible] and de[illegible]ous plexus. Acrocyanosis represents an extreme phase of this reaction, the blue being a much deeper shade than in the normal.

The color of the cyanosed skin is frequently not uniform, there usually being scattered red areas (so-called cinnabar red spots). The depth of color is generally greater in the dependent position. The white spot noted by Crocq to be caused by local pressure disappears spontaneously in a characteristic way, the color returning in from about a second to one minute from the periphery only rather than from below also is in normal skin. Local edema is in our experience fairly common. It may produce merely a sensation of tightness or in extreme instances may even reach the stage where "pitting" is possible. This is not seen in the Raynaud's syndrome.

Gangrene and ulceration do not occur in acrocyanosis except where frostbite or some other factor enters the picture. This is in contrast to

Raynaud's syndrome. When lesions, traumatic or otherwise, do occur, however, they tend to become septic and heal with difficulty. Another feature of interest is the remarkably slight disability noted in even advanced cases.

Occasionally the follicles of the skin become abnormally prominent. The sweating of the palms and soles of the feet offers a marked contrast to the Raynaud's syndrome. We have seen patients from whose hands sweat would drop regularly and very frequently, that is, one to five drops per minute. This occurs in a cool environment in which gross sweating would ordinarily be absent. Kuno has shown that perspiration at low temperatures occurs more on the palms and soles than elsewhere, is increased by hyperemia, and failing to evaporate collects on the surface. This really represents the condition of acrocyanosis. When the circulation to the skin is shut off, perspiration becomes minimal and the skin becomes dry as in the Raynaud's phenomenon.

Increased sweating keeps the stratum corneum moist and pliable. In patients who do little manual labor the layer tends to atrophy and the amount of perspiration being greater than necessary keeps the skin wet. In day laborers, by contrast we find extremely thick horny dry skin.

Kuno has also shown that mental stress will cause sweating of the palms and soles. In cool environment this produces chilling of the part and in susceptible individuals tends toward acrocyanosis. In certain cases cyanosis of the face and other parts may be seen. Livido reticularis is not an unusual accompaniment.

In general, the symptoms and signs are much more marked in winter than in summer. Even in extreme cases the normally palpable arteries are always patent, the circulatory interference being due to spasm of smaller vessels.

Etiology: While many etiological theories have been suggested only six factors thus far considered seem worthy of discussion.

Cold: Cold seems to be the one universal precipitating factor, producing attacks in susceptible individuals—whereas, heat relieves them. While cold may well be considered the most important external factor it cannot be the sole cause or the disease would be more universal in persons exposed to sufficiently low temperatures.

Mental Disease: Acrocyanosis while relatively uncommon among normal individuals is very common among mental disease patients. (About forty-five per cent in one series of 110 mental patients studied.) It should be noted, however, that many mental patients of identical types may not have this syndrome and numerous cases have been seen in normals though more commonly in neurasthenic females than in other groups.

Activity: Stern found that it occurred about two and one-half times as frequently in those patients who habitually stood or sat about, indifferent to chilling, as in the normally active. In following his cases for four years he observed that twenty-six per cent showed decreased activity leading to greater cooling of the extremities with increased acrocyanosis. Twelve per cent showed increased activity with consequent warmth and decreased

acrocyanosis. The remaining fifty-eight per cent showed no changes either way.

Endocrine Relationships: This is in a state of debate at present. We admittedly cannot test accurately the activity of many of the endocrine glands. Stern does not believe there is an endocrine basis for this condition and he may be entirely correct. We have noticed in our series, however, a number of endocrine types of individuals and have had fairly consistently lowered basal metabolic rates. These have been in the low normal or somewhat subnormal range rather than extremely low. The sexual ratio is about equal in contrast to Raynaud's syndrome which occurs more frequently in the female (seventy to ninety-five per cent of all cases according to the authority). Most cases occur between twenty and forty-five years of age. The extremes in Stern's series were four to sixty-seven.

The relationship to the autonomic nervous system must be considered more carefully since interruption of these fibers by ganglionectomy benefits this condition, according to White.

Avitaminosis, especially deficiency in vitamin A, has been associated with this condition. High vitamin intake has been accompanied by improvement in a few instances. Much further work must be done before this relationship can be considered as established. As present skepticism is justified. Other factors such as blood pressure, blood count, Wassermann tests, blood chemistry, etc., have been unproductive in this regard.

The fundamental etiological factor must be sought for further, the present status of knowledge in this regard being inadequate.

Physiological Pathology: Normal skin cooled to the point of cyanosis can be somewhat blanched if elevated to about heart level, demonstrating lack of venous obstruction. This is also true of acrocyanosis. It was also demonstrated by Lewis and Landis that the white spot of Crocq disappears spontaneously and *leaves no trace* since it is due solely to displacement of blood from the area by the pressure used. Local trauma produces a red area within the cyanotic zone which appears to demonstrate a breakdown in what is otherwise arteriolar obstruction. This redness is greater in extent than the original area of the trauma. Furthermore, if the circulation to an acrocyanotic finger is occluded for from five to ten minutes following release the reactive hyperemia extends from 1 to 2 cm. proximal to the site of obstruction instead of being limited sharply to the obstructive point as in a normal finger. It is thought that these phenomena are due to a ready diffusion of the H (histaminelike) substance to the surrounding arterioles producing dilation. These phenomena fit into the hypothesis of Lewis and Landis that the mechanism of acrocyanosis is based on arteriolar obstruction. If the hand is cyanosed and a small part of it is warmed that area becomes a bright red. Similarly if a little histamine (1:3,000 solution) is injected the local skin reddens with a rise in temperature. In the Raynaud syndrome this will not occur since the next larger set of arteries are involved and this phenomenon cannot occur until they have dilated.

In testing for this condition extreme cold (1° to 10° C.) (33.7° to 50° F.), should not be used since in these as in Raynaud patients and normal individuals the exposed parts become red due to arteriolar injury, dilatation, and retarded deoxygenation of the blood.

Until recently it was felt that no organic lesions of the blood vessels were found in this syndrome. It was entirely reasonable, however, to suppose that the repeated contractions of the arterioles continued over a period of years might well produce certain changes, such as hypertrophy of the media. Stern reports having demonstrated this to be true. He felt that the medial coats of all arterioles from 30 to 150 μ in diameter were definitely thickened, at least to the upper limits of normal. He also found local edema and fibrosis of the skin together with dilatation and increase in number of the superficial capillaries. Layani claimed that various blood dyscrasias are found with acrocyanosis including prolonged coagulation time, lowering of the platelet count, etc.; Stern checked these and many other factors—concluding that no abnormality had thus far been demonstrated.

The mechanism appears to be either due to local sensitivity of the small vessels to cold or to some vasomotor action producing increased arteriolar tone. Haxthausen and Lewis favor the theory that the vessels are especially susceptible to moderate cold reacting in a diffuse manner than specifically to extreme cold injury. They do not explain the source of the increased susceptibility. Lewis feels that this is localized to the arterioles to the skin since he claims that the cyanosis is not relieved quickly by a nerve block—as would happen if the condition were on a vasomotor basis. White on the other hand suggests a purely vasomotor basis since he claims that this condition is relieved as is Raynaud's syndrome by complete preganglionic section. Obviously this point must be clarified by further work.

Treatment: The treatment of acrocyanosis must thus far be directed at decreasing the arteriolar spasm. The following suggestions are therefore made.

1. Keep the patient and the part warm, either by climate or local environment.
2. Keep the patient as physically active as possible within reason.
3. Reduce the mental strain to a minimum.
4. Ganglionectomy—preganglionic root resection.
5. Vasodilating drugs, nitrites, priscoline, roniacol, and ilidar, etc. (empirical).
6. Thyroid extract has helped certain cases in our series, if the basal metabolic rate is low.
7. A high vitamin régime empirically.

H. O. McPHEETERS, M.D.

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Varicose Veins

Definition: The term "varicose veins" is commonly used to designate the dilated, elongated, and tortuous varicosities of the lower extremities

Anatomy: The venous anatomy of the lower extremity consists of two sets of veins, *i. e.*, the deep and the superficial. The *deep veins* are placed among the muscles of the leg and thigh. They unite and form the deep femoral vein which enters the pelvis under Poupart's ligament. The *superficial veins* lie in the superficial fat. The long, greater, or internal saphenous vein, which arises in the dorsal venous arch of the foot, passes upward over the internal malleolus along the internal border of the tibia. It then crosses medial to the internal condyle of the femur, after which it passes along the inner and anterior aspect of the thigh through Hunter's canal, and terminates at the oval window in the groin, where it joins the femoral vein. This union with the femoral vein is called the saphenofemoral junction The short, lesser, or external saphenous veins collect the venous blood from the further aspect of the leg and heel. In both the superficial and deep veins the backward flow of blood is prevented by many sets of valves. Most of them are bicuspid, while a few are unicuspid. As a rule, these valves are placed distal to the opening of a tributary vein. The saphenofemoral opening is protected by a tricuspid valve.

Classification: The following classification of varicose veins according to size has been found most satisfactory:

Size 1. Veins ½ cm. in diameter.
Size 2 Veins ½ to 1 cm. in diameter.
Size 3. Veins 1 to 1½ cm. in diameter.
Size 4. Veins 1½ to 2 cm. in diameter.
Size 5. Varices larger than 2 cm. in diameter require a definite description as to their size and shape The fine superficial varices in the skin are called bursts or brushes, either rocket or spider type.

Etiology: The most important factor in the development and formation of varicose veins is the presence of congenitally weakened vein walls, which give way under the strain of hypostatic congestion and other factors which increase the venous pressure. Infection plays a greater part in the development of varicosities than has been acknowledged in the past. A hereditary factor has been found present in about seventy per cent of all cases. Pregnancy is the active cause of the development in many cases. The endocrine factor has not received the attention due it. A pelvic examination is always advisable in all extensive cases, both male and female, to rule out the presence of pelvic tumors and obstruction, such as fibroids in the female and malignancy of the prostate in the male. In actual practice, however, it is a rarity to find these conditions as the causative factors.

Direction of Venous Flow in Varicose Veins: As the walls of the veins dilate, the edges of the valves are pulled apart and can no longer function accurately. By this mechanism, the reverse flow of the venous blood becomes established and may increase until the large dilated superficial veins literally form saccules of blood, which fill or empty in accordance with the laws of gravity. As the venous blood flows upward past the saphenofemoral opening, in a well-developed case of varicose veins, a portion of it gravitates back toward the foot. This phenomenon is more pronounced when the valves are not functioning and when the leg is in a dependent position.

Diagnosis. *Trendelenburg Test:* This pathological circulation was first discussed by Trendelenburg in his thesis of 1890. His description of it was so classical that since then the method of determining the direction of venous flow has been known as the Trendelenburg test.

The clinical explanation of the Trendelenburg test may be described in the following manner: The blood from the deep veins flows outward through the saphenofemoral opening, due to the defective valves, then downward, through the superficial vein, to reenter the deep veins of the lower leg through the communicating veins, where it is again forced upward by the constricting forces of the muscles in the leg. Thus, a true vicious cycle develops which increases as the extent of the varicose veins increases

The Trendelenburg test of this reverse flow is made by having the patient lie supine with the leg elevated above the level of the body. The effect of gravity will rapidly empty the distended varicosed veins and they will quickly disappear. Pressure is then made over the foramen ovale and the patient is allowed to stand. The veins will fill and distend normally in about thirty seconds if not very extensive. If the communicating veins of the lower leg are defective and dilated, the varicose veins will fill more rapidly by this reverse flow. This is called a *Trendelenburg negative*. When the patient stands with the pressure maintained at the foramen ovale and the veins remain collapsed but rapidly fill and distend when this pressure is released, he has defective valve function at the foramen ovale and this reverse flow is called a *Trendelenburg positive*. If there is a reverse flow from both directions, then the patient has a *Trendelenburg double*. At times the reverse flow is through some of the communicating veins in the middle or lower thigh. The origin of this reverse flow is best located by the use of the *Perthe test* and by the *multiple tourniquet test of Ochsner and Mahorner*. The latter is in reality the application of the Perthe test at repeatedly higher levels. This test is made by placing a tourniquet tightly about the thigh, just below the uppermost dilated and distended varix, with the patient standing. The patient then takes rapidly about fifty steps and the varicosed segment below the tourniquet will be seen to empty, while the vein just above will remain distended. When the tourniquet is removed, the blood will be seen to flow downward, filling the veins now empty.

Any attempt at treatment of this condition should be directed at this underlying pathological reverse flow of blood (Fig. 1).

Differential Diagnosis: Very often large and small varicose veins are found in association with rheumatism, diabetic neuritis, Morton's disease,

thromboangiitis obliterans, and numerous other diseases. It is not uncommon to have a patient present himself for treatment for arthritis when, in reality, his pain and discomfort are caused by varicose veins. On the contrary, the converse may be true. In almost all of these conditions, the varicose veins aggravate the associated pathology and should be treated

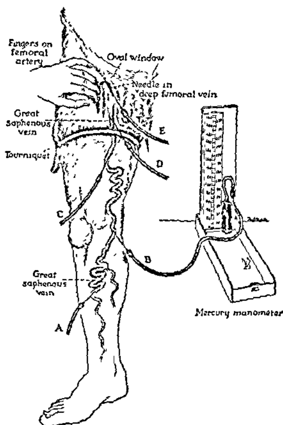


FIGURE 1. Showing technical details of the experimental work on blood pressure in varicose veins. Change in blood pressure from *D* to *A* with different postures clearly shows direction of reverse flow. (From McPheeters, Merkert, Lundblad: Surg., Gynec. & Obst.)

Complications: The commonest complications of untreated varicose veins are stasis dermatitis or eczema of the lower leg, ulcers, and infectious thrombophlebitis.

Stasis Dermatitis or Varicose Eczema: This condition of the leg is often a result of varicose veins in which there has been a change in the reactive powers of the epidermal cells, either by direct injury or by interference with nutrition. This loss of surface resistance and altered reaction is seen in acute vesicular eczema where bacteria and fungi are furnished an excellent culture media. The bacterial infections frequently exhibit a marginal spreading vesicular eruption, acutely inflamed and at times may have the appearance of erysipelas. Fungous infections of vesicular areas exhibit similar characteristics, as they do on other parts of the body, *i. e.*, peripheral spreading vesicular eruption with central healing.

The application of ointments in the acute stage frequently causes an exacerbation of symptoms present not only as a local extension of the disease, but also as a generalized, papulovesicular eruption. This may become an exfoliative dermatitis.

When the eruption has persisted for a period of time, secondary changes occur, such as hyperpigmentation, or vegetations may form, which in time appear as a dermatitis vegetans.

Other plaque-like eruptions may appear and have the symptoms and clinical picture of "lichenoid chronicus simplex."

As each recurrent attack of cellulitis, dermatitis, and fungous infection goes through its cycle of inflammation and then subsidence, the lymphatics of the lower leg become more damaged and obstructed by scar tissue than ever. This causes an increase of the edema and swelling. Ultimately we have a chronic condition of the leg which resembles that of elephantiasis. The descriptive term of "elephantoid" or "elephantiasis like" is more appropriate.

Treatment: The treatment of eruptions on the leg necessitates a proper understanding of the pathology present as well as determination of secondary factors.

There are listed below a few fundamental principles which, if observed, will facilitate treatment.

(*a*) The varicosities should be obliterated. If there is no reverse flow and varicose veins are small, size 1, or less, then simple sclerosing injections may be sufficient, but if there is a definite reverse flow then a ligation of the veins must be done wherever this may start. That may be at the saphenofemoral junction, the popliteal junction of through perforators The ligation is then followed by a thorough stripping of the main varicose veins and obliteration and injections of the remaining scattered tortuous small varicosed segments.

(*b*) Acute vesicular eruptions should be treated with wet compresses to cause maceration of the vesicular areas and subsidence of inflammation. If the irritation is severe and extensive the lower extremity is usually badly swollen. If such is the case then the patient must be at bed rest with the leg in high elevation until the edema is gone. Solutions frequently used are: Normal saline solution; lead acetate and alum solutions (diluted one to ten); solution of copper sulfate one per cent and zinc sulfate two per cent (diluted one to sixteen); potassium permanganate 1 to 5000 solution; and boric acid solution. These should be used until the eruption has become subacute or involuted.

(*c*) Pyogenic infections are best treated with mild antiseptic and astringent wet compresses, such as mentioned above. If, however, the infection appears erysipelas-like, erythema doses of ultra-violet light give prompt and excellent relief. X-ray treatment is even more effective. The sulfa drugs and the antibiotics are used frequently.

(*d*) Subacute or chronic eruptions should be judiciously treated with weak tar ointments, such as crude coal tar, oil resci, oil of cade, etc., one to two per cent in a suitable hygroscopic ointment base. Care should be exercised in the use of ointments, as vesiculation may reappear. Under

such circumstances treatment should be as outlined in the acute stage X-rays should be used cautiously after maximum improvement has been obtained by local treatment. Their use is of great value but x-ray treatment must be given only by the specialist.

(e) Fungous infections may be treated as suggested in the acute vesicular eczema, except that the other foci of infection (toes, etc.) should be treated simultaneously. Some of the fungous ulcerations respond quickly to the use of aureomycin ointment.



FIGURE 2. This leg had been emptied of venous blood by elevation A rubber tourniquet was then applied tight enough to compress the internal saphenous vein On lowering the leg a sudden filling of the medial group of varicosities on the calf took place The communicating veins between the deep and superficial systems are incompetent here

(f) Mechanical support. Following disappearance of the acute symptoms, supportive treatment should be instituted, as outlined in another part of this discussion.

Varicose Ulcers: Ulcers develop as the result of trophic changes in the lower part of the leg, and are usually secondary to trauma or local infection. This trauma or infection is so severe as to develop a localized thrombus of the terminal arteries and produce an atrophy of the tissues with local edema. The associated varicose veins continue to inundate and saturate the area, already trophically below par, with a stagnant, poorly oxygenated, venous blood (Fig. 2). The condition becomes progressively worse as long as the patient is on his feet without support, and, as a rule, the ulcer with its associated cellulitis continues to spread until the patient is forced to bed. With the patient's foot in high elevation.

gravity will draw the fluid out of the tissues and the condition locally will rapidly approach normal. A patient may present himself as having experienced many cycles such as this. Every time the patient goes through this cycle of trauma, infection, congestion, ulceration, cellulitis, bed rest, elevation with its relief of congestion, and finally healing of the ulcer with a large amount of scar tissue left locally, the trophic state of the extremity in that area is still lower than before the last attack.

Treatment: In considering the treatment, an endeavor should be made to correct the pathological factors which have caused the ulcer to develop The first problem, then, is to overcome the congestive factor. This may be accomplished by any one of the following methods or preferably by a combination of them all: (1) Obliteration of the varicose veins leading into the ulcer area; (2) putting the patient to bed with the foot and leg in high elevation and the application of routine hot wet packs; (3) the application of Unna's paste, boot or bandage; (4) applying the rubber sponge and Ace bandage and having the patient walk five blocks every four hours in addition to frequent short walks; (5) doing a preliminary ligation of the great saphenous vein at the foramen ovale if the veins are large. The varicose veins of the thigh and lower leg are then stripped as completely as possible and the scattered tortuous small varicose veins are injected as soon as possible thereafter.

(*a*) *Injection Treatment:* This is reserved for the small tortuous terminal segments of the varicose veins not stripped.

(*b*) *Operative Treatment:* The simple ligation of the great saphenous at the saphenofemoral junction is not enough and when nothing else is done it should be classed as meddlesome surgery and should not be done. Following the ligation we must obliterate the varicose veins below by careful stripping, by careful follow up office injections. No operative treatment should be done in the presence of an active infection such as severe dermatitis, acute cellulitis, or open ulcers with severe local infection. Get the infection under control first and then obliterate all varicose veins. The active treatment of the bad ulcer will be given in detail later. At times a large varicose vein will pass nearby and under an open ulcer. Often this can be stripped to the good skin area below with rapid healing of the ulcer. In cases with extensive cellulitis about the ulceration, and with a severe secondary infection about the ulcer, it is best to apply routine, hot, wet packs applied widely over the infected area for three to four days first before the injections are started. This is done with the idea that the veins cannot thrombose and organize as well through a badly inflamed area with an acute cellulitis, but will respond quickly as soon as the inflammation has been removed and the tissues softened up

(*c*) *Bed Rest:* In the past the treatment for varicose ulcers has been rest in bed with the leg elevated, because the patients have found that as soon as they get off their feet and elevate the foot, the leg feels better. This is due to the fact that gravity draws the blood from the foot and the congested area and tends to draw out the edema which is present and causes pressure on the nerve terminations, thereby causing pain. Many

cases of varicose ulcers will heal rapidly as soon as the patient goes to bed in the manner directed, for then the trophic state of the tissue will approach normal quickly, and the healing process will go on the same as with an open sore elsewhere on the body. This will not be the case, however, in the more chronic and recurrent types, as some of these persist even though the above treatment is carried out.



FIGURE 3. Typical extensive varicose ulcer. Small white areas in ulcer are seed implants after method of Braun, ten days old Circle shows size of original ulcer. Cross marks show location of middle of ulcer after dressings are applied so rubber sponge can be bandaged directly over ulcer.

(*d*) *Unna's Boot or Cast:* For the past half century the application of the zinc glue bandage, according to the formula of Professor Unna, commonly called Unna's paste or boot, has been used for the supportive treatment of varicose ulcers. This material supports the extremity and tends to relieve the congestion. The great majority of the results of this treatment are due to the support obtained. Some physicians still use it applied directly over the open ulcer, changing the cast every four to ten days. It is used less now, but still remains one of the most common methods of supporting the extremity during the weeks and months following healing and the patient's discharge from active care. Unna's paste is now supplied in tightly sealed cans with the paste worked into a four inch gauze bandage, ready for application.

(*e*) *Rubber Sponge or Venous Heart:* The modern treatment for varicose ulcers dates from the time Professor Nobl, of Vienna, suggested

the rubber sponge pressure over the ulcerations, together with the application of a firm cotton elastic bandage. By means of the bandage, the leg is supported so that further edema and swelling cannot take place, and by means of the rubber sponge, continuous gentle pressure massage is maintained over the ulcerating and inflamed area, so as to force out all the edema and fluid. This has been termed the rubber or venous heart in the treatment of varicose ulcers (Fig. 3).

(*f*) *Treatment of the Ulcer:* The actual treatment of the ulcer itself consists of the application of a mild ointment and sufficient fluffed gauze dressings to absorb the discharge and keep it from coming through on to the bandage. If the granulations have a poor blood supply and are indolent, or if they are excessive and overgrown, they should be treated with ten per cent silver nitrate for the purpose of stimulation and to hold them in check. At times, a stimulative ointment is of much help. The application of one inch strips of adhesive over the ulcer area will hold the excessive granulations in check, while the Ace bandage is used for continued support for the lower leg.

Iodine is of definite value in the treatment of the more chronic varicose ulcers. This is probably due to its effect as a tissue softener and solvent. Lugol's solution is given, ten drops, three times a day. Parathyroid gland extract is of much help in some cases and should be used in the more resistant ulcers. Except for the cost, it would be well to use it as a routine. Most of these cases have a low basal metabolic rate and the peripheral circulation is speeded up and improved by giving thyroid, 0.06 Gm. (1 grain) twice a day, until the patient has a plus 12 to 15 B.M.R.

Most patients with bad chronic recurrent varicose ulcers are anemic and physically below par. They may have a poor appetite and eat little. They may need protein or even a blood transfusion.

(*g*) *Continued Support:* When the ulceration has healed and the trophic state has been brought to the best degree possible, support to the extremity must continue for a long time. This is necessary because the vitality of the tissues is not sufficient to prevent a recurrence. The patient then wears a Unna paste boot, a rubber elastic stocking, or the elastic bandage for a period of two or three months. Sufficient regeneration may then develop in the tissue so that the patient can go either part or all of the time without this support. In the more extensive and chronic cases, however, the patient is forced to wear the elastic bandage or stocking practically all the time. By doing so, however, he can be assured of avoiding future ulcerations, and should they occur, they can be rapidly healed.

(*h*) *Surgery of Varicose Ulcers:* In some of the more resistant ulcers some surgeons advise the undercutting of the entire ulcer area. This will destroy any varices underlying the area. It is argued that new lymphatics are developed with the deeper lymphatic system and that the stasis is thus improved.

In the more resistant and extensive cases, resort may be had to skin-grafting. The simplest type is after the method of Braun (Fig. 3) where small sections of the epidermis, twice the size of the head of a pin, are

removed under local anesthesia and then buried in the granulating base of the ulcer. Many of these seeds are buried through the ulcer base and the usual dressing is then applied with the patient up and walking about with the Ace bandage for supportive treatment. The seed implants begin to appear in about seven to ten days and then rapidly spread, thus shortening the period of healing.



FIGURE 4 *A*, Superficial ulceration with ringworm ... *B*, Tuberculous ulcer *C*, Elephantiasis with small ... thrombophlebitic ulcer with lymphostasis (deTakáts, ...

In large ulcers the Thiersch pinch grafts ... cases the best results are obtained by a comp... and scar tissue area, to be followed with the ... full thickness skin-graft, or even with a pedicl... d a dermatome split-thickness graft takes well ... un should not be used except in cases with very ... and tions. Do not graft until the area is clean and ... watery. Skin-grafts should be used more oft...

Phlebothrombosis and Thromboembolism. ... ion ing of the vein lumen with a blood clot but ... urs, present. This is potentially the most serious ... uld tions. It often occurs without symptoms ... ng.

the deep veins of the lower leg or thigh during the first few days postoperative or postpartum. It is merely a stagnation thrombus. The first signal may be a slight rise of fever and pulse, or a tenderness deep in the calf, noticed while the nurse is giving the bath. There may be some pain on forced extension of the knee. In a phlebothrombosis there is no inflammation present to anchor the clot or thrombus. For this reason it may become loose and float toward the heart and cause a pulmonary embolus with slight exertion and activity.

The treatment of this condition varies widely with different surgeons. Some advise a bilateral deep femoral ligation as soon as the condition is suspected. The author prefers to hesitate and use heparin and dicumarol to keep the prothrombin activity about twenty-five per cent of normal. If a pulmonary embolus should develop then a deep, femoral ligation is often done, as a fatal embolus does occur in twelve per cent of such cases who have already developed one pulmonary embolus.

Any patient having septic emboli or repeated pulmonary emboli should have a vena cava ligation. This, however, is heroic treatment and is not advised as a routine.

The most important thing in the treatment of phlebothrombosis is its prophylaxis. For this we advise leg exercises in bed, adequate hydration, respiratory stimulation, and early ambulation. Avoid Fowler's position as much as possible and watch for and avoid ileus.

Thrombophlebitis: By this term is meant the formation of a thrombus or clot within the lumen of a vein, the result of an inflammatory reaction, and attached to the wall of the vein. This may partially or completely block the lumen of the vein. It may be due to the introduction of a chemical solution into the vein, as in the injection treatment of varicose veins, or it may be due to the presence of an infection in the blood stream and thus give rise to the inflammatory condition known as "acute infectious thrombophlebitis."

The latter condition may affect either the superficial or deep group of veins. The deep veins are more commonly affected associated with pregnancy, pneumonia, typhoid fever, general infections, and operations, while the superficial group often becomes inflamed from no apparent cause. The infection in these cases may be from hematogenous or local sources.

Aschoff states that a slowing or stagnation of the blood stream is the first essential to the development of a thrombophlebitis. The second is a change in the blood constituents, and the third is an injury, traumatic, infectious, or chemical, to the vein wall.

Associated with the thrombophlebitis there may develop an obstruction to the lymphatic system of the leg or thigh. This gives rise to the swollen, white, and edematous leg so commonly seen postpartum and formerly called milk-leg.

Infectious thrombophlebitis of either the superficial or deep systems, is always a potential source of pulmonary emboli with fatal termination It is for this reason that the examination of these cases should be done carefully and with but little manipulation and no massage.

Treatment: This is considered best under separate headings:

1. Conservative: Bed rest with the involved extremity elevated and the application of routine hot wet packs widely applied over the area with the lower leg in high elevation.

2. Systemic: Papaverine hydrochloride has been advocated for its vasodilating effect on the peripheral circulation. This is given intravenously 15 mg. (¼ grain) every four hours.

3. Sympathetic Block: Ochsner enthusiastically advocates the injection of the lumbar sympathetics with one per cent novocain for those cases with deep vein involvement. This relieves the vasospastic block that has developed and causes a rapid subsidence of the edema and pain. The author believes it is of utmost importance and advises it in every case. Some surgeons use metycaine 1.5 per cent caudal block.



FIGURE 5. Segment of a vein 605 days after artificial thrombosis. Fibrous tissue completely obliterates lumen. Small spaces in central portions represent dilated capillaries and are probably remnants of those which took part in process of organization. Note preservation of media. (From Lufkin and McPheeters, Surg., Gynec. & Obst.)

K. Sigg, of Basle, Switzerland, has advocated and used butazolidin extensively. He reports excellent results. It is advised to give 100 mg. q.i.d. for four days and then stop. If continued it may have a definite destructive effect on blood metabolism.

4. Surgical: If the infectious thrombophlebitis involves only the superficial varices of the mid and lower third of the thigh, some authors advise complete excision of the infected area with ligation of the vein high above.

Martin M. Fisher and Nathan D. Wilensky of New York advise and use trypsin intramuscularly. It is supposed to set up a metabolic chain reaction in the tissues that seems to help dissolve the thrombus and stimulate healing. Their reports are enthusiastic.

Antibiotics are of little value and seldom used.

As a rule the thrombus has extended to the saphenofemoral junction when first seen. Wide application of routine hot wet packs, q. two hours, checks the process and eases the pain. The thrombosed segments should be incised and the thrombus curetted out. This causes rapid healing.

With the 10 cm. (four inches) ACE bandage firmly applied about the lower leg, ankle, and foot they must walk briskly for five minutes both night and morning.

Ligation of the deep femoral vein at the groin has been advocated for severe cases involving the deep femoral vein but this is radical and extreme.

If a patient has developed a pulmonary embolus then there can be no question but that a ligation of the superficial femoral vein on that side should be done. If they have not, then the conservative treatment de-



FIGURE 6. Specimen removed 760 days after injection. In this portion of vessel obliteration has probably taken place by two separate processes At right, lumen is filled by hyalinized fibrous tissue containing traces of blood pigment At left there has been a tremendous hyperplasia of intima, probably into an empty "cleft" or area of softened blood clot. Thickened intima contains no blood pigment. (Lufkin and McPheeters: Surg., Gynec. & Obst)

scribed, with the additional use of the anticoagulants, heparin and dicumarol are used by preference. A full dose of heparin, 200,000 units, is given during the first twenty-four hours. Dicumarol, 300 mg. is given at the onset with 200 mg. on the second day and 100 mg. on the third day. The prothrombin time must be carefully watched and taken every twenty-four hours. It should be kept about twenty per cent or twenty-five per cent of normal by subsequent doses as needed.

The patient should be kept in bed with the routine application of the hot, wet packs and walking b.i.d. for one week after all pain, soreness, and fever have disappeared. If there is any swelling at the end of this time, it is best that the patient wear an elastic bandage on the leg as long as it lasts. If a case of infectious thrombophlebitis is not recognized and properly cared for, permanent swelling of the leg, ulcerations, eczemas, etc., may eventuate.

Treatment of Varicose Veins. ***Operative Treatment:*** The old vein-stripping or operation with multiple separate ligations is no longer the treatment of choice for the average case of varicose veins. The early case can be well treated by the simple injection method, a discussion of which follows. The extensive far advanced case with a marked reverse flow must

first have a high saphenofemoral ligation above all the tributaries and flush with the wall of the femoral vein and then either a retrograde injection of the distal veins or a thorough stripping of them with the improved modern technic. The mortality from the operative treatment with vein stripping was formerly seventy times greater than following the modern injection therapy.



FIGURE 7 Extensive case of varicose veins of great saphenous system This shows before and after treatment by saphenofemoral ligation with retrograde injection of sylnasol. Such an extensive case can best be treated with a saphenofemoral ligation with retrograde injection of sylnasol Such an extensive case can best be treated with a saphenofemoral ligation with stripping of the main saphenous vein and then by blunt dissection of the large tortuous segments through scattered incisions Those varices remaining after two months are then separately injected with sylnasol

Injection Treatment: (1) HISTORY: The injection treatment of varicose veins dates from the work of Chassaignac, in 1853. Pravaz had invented the hypodermic syringe two years previously, but it was Chassaignac who first suggested its use in the obliteration of varicose veins.

The solutions used at first in the injection treatment were strongly corrosive and coagulating. Carbolic acid, tincture of iodine, perchloride of iron, and other solutions have been used. Many complications have developed. Sloughs of the vein and the surrounding tissue were a very common occurrence.

(2) PATHOLOGY FOLLOWING INJECTION TREATMENT: In order to determine the result which developed within the vein following the injection of the sclerosing solution, sections were removed from the great saphenous

vein six inches above the knee. The microscopic work was done by N. H. Lufkin, pathologist at the Minneapolis General Hospital. A brief summary of his work bears out the following facts (Figs. 5 and 6).

1. That a thrombus develops according to the theory of Aschoff.
2. That the direct injury to the vein wall is not as violent as has been commonly supposed, except with mercury bichloride and quinine urethane.
3. That the endothelial cells do not, as a rule, slough off and disappear.
4 That there undoubtedly is a change directly on the blood constituents



FIGURE 8. Typical extensive case of varicose veins, showing the accessory vein through thigh and inner knee which can be stripped well to the mid-third of lower leg The tortuous mass in the lower third must be removed by multiple incision and blunt dissection. It also shows the terminal saphenous at the ankle leading to the distal venous arch

5. That following the irritation of the vessel wall and the change of the blood constituents, fibrin is laid down at the point of injury, and the thrombus proceeds from that point.
6 That organization develops by proliferation of the endothelial cells outward into the thrombus, with an ultimate complete organization of the thrombus formation

(3) CHOICE OF SOLUTIONS: At the present time, the solution most commonly used in the United States is sodium morrhuate in three and five per cent strengths.

Other well known and commonly used preparations are soricin, monolate, sotradecol, and sylnasol. Sylnasol is the solution used and preferred by the author.

The combined sugar and salt solution with benzyl alcohol, the solution of invert sugar, and the salicylate preparations are still used, but have been discontinued by most physicians due to the associated cramp induced following injection. All these last solutions as well as the quinine and urethane sol. will cause severe sloughs if accidentally injected outside the vein.

(4) INDICATIONS: All cases of varicose veins should be treated unless these varicosities are definitely proven to be compensatory, or unless an associated cardiovascular condition is so extreme as to necessitate the confinement of the patient to bed (Fig. 7)

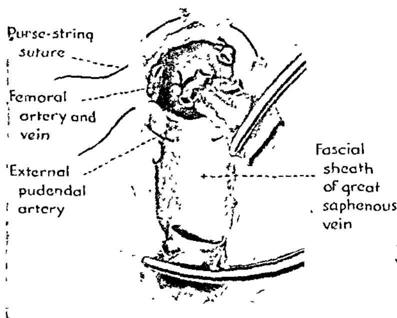


FIGURE 9. High saphenofemoral ligation, showing the placing of the ligature flush on the wall of the femoral vein above all tributaries The purse-string suture is in place and the distal stump below remains clamped

(a) *Varicose Veins and Pregnancy:* Some surgeons treat varicose veins during pregnancy the same as at any other time. The author cannot agree and prefers to treat them palliatively by using the elastic bandage for the lower leg and elevation of the lower extremities to thirty-five degrees for one-half hour t.i.d throughout the pregnancy. He agrees with MacAusland who advises the use of estrone and progesterone, deep intramuscularly from the second to the sixth month. It very definitely helps to check the varicose vein development.

(b) *Bursts:* Bursts of the rocket or spider type should be treated for cosmetic purposes only, even though they may not be painful (Fig. 8). Use fine foam only for the injection of bursts and drain out any softened thrombi after seven to ten days.

(c) *Labial Varices:* Labial varices may be successfully injected and should be treated if they are painful.

(5) Contraindications: The contraindications to the injection treatment may be stated briefly as follows:

(*a*) Those cases that have had a recent local or extensive infectious phlebitis are not treated unless a ligation is done at the foramen ovale for a progressively ascending phlebitis. It is wise then to inject the distal segment at the time, otherwise use local heat.

(*b*) Patients who have an active infection at some distant focus in the body are considered poor subjects for the injection treatment.

(*c*) A patient who is confined to bed should *not* be injected.

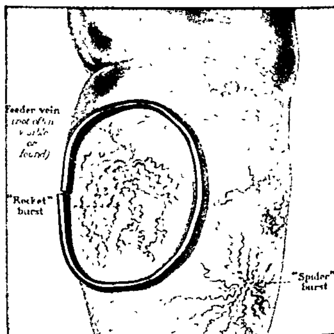


Figure 10 Burst type of varicose veins, both rocket and spider type This shows the varicose vein occluder in use (H. O McPheeters. "Varicose Veins," F A Davis Co, Philadelphia)

(*d*) Compensatory varices resulting from obstruction of the deep veins of the leg should not be injected while they are compensatory and until the deep veins have become recanalized.

A patient should not be injected while convalescing in bed, postoperatively or for a medical condition, because of the fact that the circulation of the extremities is greatly retarded and increases the liability of pulmonary embolism.

(6) Compensatory Veins. The possibility of a complete obstruction of the deep veins of the leg following an infectious thrombophlebitis and the subequent development of compensatory superficial varices has been greatly overemphasized

The Perthe and tourniquet tests are of great value here and should always be used in the doubtful case. If the deep veins are blocked from the old thrombosis, the patient will complain of pain and distress when he

walks with the tourniquet applied tightly about the thigh. The veins will distend and feel more tense and thus give a negative Perthe test The varicose veins in such a case should *not* be injected.

(7) Equipment: (*a*) *Syringe:* The operator should at all times have absolute control of his injections, and should be able to apply either positive or negative pressure on his syringe at any moment without



Figure 11 Before and after treatment by high ligation and use of five per cent sodium morrhuate as a sclerosing agent (McPheeters Surg, Gynec & Obst; Internat. Abst of Surg)

changing the position of his hands or fingers. This may be done well with any good 2 cc. syringe when using the small doses of any solution, or the 5 cc. and 10 cc. Luer Lok syringe when using the larger doses of sugar or the sugar and salt mixture.

(*b*) *Needles:* The needles used for the injections should have the special medium bevel and should always have a sharp point. For the thinner solutions, a 23-gauge needle should be used, because it has been observed that the smaller 25- or 26-gauge needles are too easily forced through the wall of a vein as the injection is being made. Many times an operator using the finer gauge needle is surprised to see his injections are being made outside the vein, even though it may not have occurred to him that

his needle point had changed its position. This mistake is less apt to occur when a 23-gauge needle with the medium bevel is used.

(c) *Tourniquets:* A good, 12 mm. (½ inch), soft, pararubber tubing is best for tourniquets.

(8) PREPARATION: In the preparation of the patient for injection, asepsis is an important consideration and should be used here the same as in any other operation.

(9) PRELIMINARY LIGATION OF THE GREAT SAPHENOUS VEINS (*Fig.* 9): All experimental and clinical evidence definitely proves that the venous flow in an extensive, well-developed case of varicose veins is reversed and flows from the foramen ovale downward. Oftentimes the upper end of the great saphenous for the last inch at the saphenofemoral junction is dilated much larger than the vein below. This in reality forms a funnel and directs the venous pressure from the main femoral vein into the great saphenous, which is now devoid of its valves at that point, due to the dilatation and valve injury. Thus it is clear that the hydrostatic pressure of the venous blood downward in this funnel will gradually recanalize any veins that have been *treated only* below the knee; that have not been treated with stronger solutions in the thigh to the groin; or where the operator was unable to empty the great saphenous vein and thus keep the solution in concentrated form. In fact, there will be a recurrence of all varicose veins that are not well thrombosed to the femoral vein at the groin. Knowing the above to be *true*, the writer now advises a preliminary ligation of the great saphenous at the groin in all cases where there is a definite reverse flow from the saphenofemoral junction or elsewhere.

It is very essential that this ligation be done at the saphenofemoral junction and above all the collateral veins, as a complete recurrence can rapidly develop through these collateral tributaries in the last upper two inches of the great saphenous vein. The vein is always located by the percussion impulse test (P.P.T.), and a vertical mark is made over it at the groin. Another mark is made crossing this one, one inch below and parallel with Poupart's ligament. This latter scratch mark with the tip of a scalpel or a blue grease skin pencil is best for this purpose. A felt pen and india ink is even better. This incision is preferred by most operators and is the one preferred by the author. The anatomical location of the vein, two inches below the foramen, may vary one inch and this will not matter with the transverse incision. Again, the transverse incision permits of greater traction and exposure upward and the foramen is usually located 5 cm. (2 inches) above this incision. The transverse incision also permits the operator to avoid the line of skin maceration and infection in the groin. This cannot be stressed too much. Edwards, of Boston, locates the vein by measurements from the pelvic tubercle, but it is more definite and clear if done by the percussion method. If large, open, perforating, or communicating veins should be found permitting a marked reverse flow in either thigh or lower leg, they too should be ligated either at the same time or later (*Fig.* 13). The operation is usually done under novocain so as to permit the patient to walk immediately following the operation. This is very important.

The patient should be up after the operation. They are instructed to walk briskly for at least five minutes out of every hour for the first twelve hours. The walking will definitely aid the circulation and preclude the possibility of embolus formation from the extension of the thrombus to the deeper veins and other veins not injected but in which the blood is more or less stagnant.



FIGURE 12 Extensive bursts with feeder veins (Courtesy of Dr A. F Bratrud, from McPheeters. Surg., Gynec & Obst.; Internat. Abst of Surg)

10. STRIPPING: Although all surgeons agree that a carefully done high saphenofemoral ligation must be the first step in the care and treatment of the far advanced case of varicose veins with the definite reverse flow, many believe that they can get better end results by doing a careful job of stripping the distal veins as completely as possible and later inject the remaining varicose veins. After having done 6500 vein ligations with retrograde injections and 4000 ligations followed by the stripping technic, I am convinced that the high ligation followed by thorough and complete stripping of all the varicose veins possible with blunt dissection of the tortuous groups and the careful follow up injection of remaining scattered segments at a later date gives the best end results of any method of treatment today.

The old Mayo stripper has gradually given way to the use of the intraluminal strippers of Linton, Babcock, and Meyers. With the patient in

about seven to ten degrees Trendelenburg position the small end of the stripper is passed down the vein as far as it will go. The flexible stripper can often be passed to below the knee. A small incision is then made over the tip and the vein with stripper is picked up, the vein sectioned and the stripper, about which the upper end of the vein has been firmly tied, is pulled downward and out through the lower incision. The large end of the stripper prevents it from inverting and the vein is forcibly torn from its branches. It is surprising how quickly the hemorrhage from the torn veins subsides. Firm continuous pressure controls it well. With repetition, one varicosed segment after another is removed. The very tortuous segments are separately ligated and removed when possible. If possible the veins are stripped to the ankle. Both the long and short saphenous veins are removed if involved. Pressure pads are then placed along the course of the veins and firmly bandaged in place using elastic adhesive elastoplast. The patient is returned to bed with the foot of the bed elevated on shock blocks for forty-eight hours, getting up and walking as soon as he is out of the anesthesia, usually three hours postoperative.

The support is removed from the thigh after seven days but maintained on the lower leg. Subsequent follow-up injections into the remaining varices are given about one month later and then weekly until all are cared for. Support is maintained on the lower leg as long as it is sore, tender, or swollen. After the sutures are removed local moist heat and hot baths help relieve the soreness. All patients must be seen yearly for the care of new varices which may form, just the same as with any other method of treatment.

(11) Technic of Injection Treatment: After the proper solution has been chosen, the next important principle in the treatment is to keep the solution localized and under the proper concentration in the varix which is to be treated. The patient is placed in the supine position in order that the veins may be emptied as much as possible by the force of gravity The tourniquets are placed about the extremity, just snugly enough to block the superficial veins, and at such distances apart as will best help to localize the injected solution. In some cases they may be only a few inches apart, and in other cases they will best suffice with one placed about the knee and another high at the groin The sclerosing solution is then injected into the varicosed loops between the tourniquets, where it is retained and localized for about two or three minutes, except for that which passes through the communicating veins into the deep veins. If the veins are collapsed, making it difficult to insert the needle, a small loop or vein may be distended by gently milking the blood from the varix into a small segment of vein at the site where the injection is to be made There is always enough blood present to distend one small loop by itself in this manner. The needle should then be inserted very easily into this loop. The other loops gradually distend with blood so that the operator will have no difficulty in introducing the second needle. After the sclerosing fluid has been injected into the vein, the needle point is lifted upward toward the skin and thrust onward through the vein wall so that the lumen of the needle rests outside the vein. The needle thus transfixes

the vein and in this way acts as a cork at the site of the puncture in the vein wall and prevents leakage during the next two or three minutes, while the fluid is bringing about its thrombotic effect in that segment. After the loops have been distended with the fluid for two or three minutes, the needles are withdrawn and pressure sponges of plain gauze or cotton are strapped over the site of the needle puncture to avoid further leakage until the puncture in the vein wall is closed with a clot.



FIGURE 13. Typical varicose ulcer on the inner aspect of the calf with a venous pool above the ulcer. There is a second small ulcer below the malleolus, which took more time to heal than the large one Note the absence of induration or lymphostasis. (deTakáts. Surg, Gynec. & Obst)

In some extensive cases, the needle is introduced into the lowest distended vein and then the leg is elevated to drain the varices. The solution is injected as the leg is lowered. The back pressure through the communicating veins will then hold it localized. When the veins do not stand out sufficiently so that the needle can be introduced, the patient should be treated in a sitting position. The nearer empty the vein when the solution is injected, the more perfect will be the result. A small ½ cc. dose of the solution may be injected as a test dose in any case where a possible allergic reaction may be suspected. This seldom occurs but it is very distressing when it does. If a test dose should be given with no reaction then the regular injections should be started in not more than forty-eight hours and

the case continued until completed. The small test dose might stimulate sensitivity. Never should more than a total of 5 cc. (1¼ drams) be given to any patient at one treatment at the office. This is also best divided into scattered doses of 0.5 to 0.75 cc. (8 to 12 minims).

When treating the last loops along the trunk of the great saphenous in the upper thigh, it is best to have an assistant hold extreme pressure at the saphenofemoral opening. This is done not for fear that the fluid will enter the femoral vein and cause damage, but because it further localizes and retains the solution in the great saphenous vein until the desired sclerosing effect is obtained. In this way it may be hoped to produce a firm thrombus of the great saphenous vein up to and including the saphenofemoral opening In the same degree that this result is accomplished, so will the results be perfect and the organization be permanent. If this is not done, a recurrence of the varicosed condition may be expected, due to the hydrostatic pressure of the blood column from above bearing downward through the saphenofemoral opening.

(a) *Percussion Pulse Transmitted (P.P.T.) Test:* Oftentimes, it is impossible to locate the great saphenous vein above the lower third of the thigh even though the varices are extensive. By means of the *Schwartz test*, which the writer has discussed under the name of the "percussion pulse transmitted" or P.P.T., it is possible to locate the great saphenous vein even though lying deep in the fat. The explanation of this test is made on the principle of hydrodynamics and the conduction wave along an elastic tube filled with water. With the patient standing, the prominent varicosed loops of vein about the knee or below are tapped with the fingers of one hand, while the fingers of the other hand rest gently but firmly along the course of the great saphenous in the thigh. The impulse made by tapping over the lower loops is carried along the blood column in the vein upward toward the groin, being the direction of least resistance, and is thus easily perceived by the palpating finger. By this method the great saphenous may be located in its course through the upper part of the thigh to the saphenofemoral opening in practically all cases, even though it cannot be seen or found by the usual palpation technic. The impulse is much more perceptible and stronger in a proximal direction, due to the lesser blood volume being displaced against the force of gravity.

Varicose veins occurring during and complicating pregnancy are best treated palliatively as described elsewhere. The pain in the labial varices is relieved in four to six days with the *hormone injections.*

(12) Complications Following Injection Treatment: In the past, many of the complications which followed the injection treatment were due to the violent and caustic solutions which were used, to the lack of asepsis, and to a lack of a finer degree of technic. If these obvious errors in technic are avoided, any physician should be able to do the work satisfactorily.

(a) *Pulmonary Embolism* is the most feared complication developing after the injection treatment and is practically the only one which may prove fatal. This complication is rare It has occurred but once in the

author's practice during the course of treating over 35,000 patients with varicose veins.

(*b*) *Periphlebitis:* Periphlebitis is seen less frequently now than formerly, due to better judgment as regards the solution used, its strength, and the quantity injected. With experience, this complication can be eliminated almost entirely. The object of the treatment is to develop a chemical phlebitis, in the hope that the destructive process may be sufficient to cause a thrombus adequately firm to induce a complete organization. The treated veins are tender but may be supported by bandages, elastic stockings, or adhesive strapping during the few days following treatment, and thereby give the patient much more comfort and make it possible for him to continue his work.

(*c*) *Sloughs* have occurred, do occur, and will always occur because, through a breach of technic, even the most competent surgeon may inject a small amount of the solution outside the vein wall. The tissues then become red, inflamed, and tender, but will respond well to local moist heat and support. If, in using the sugar or the sugar-salt mixture, 2 cc. (½ dram) should get outside the vein, a slough certainly would develop. In using the quinine-urethane solution, as little as two drops injected outside the vein may cause a slough. Sodium morrhuate and sylnasol are less likely to cause a slough than the other solutions. From this it is evident that the best treatment for sloughs is preventive. In case the solution is injected outside the vein, the immediate infiltration of the area with normal saline will often stop the destructive process.

Active Treatment of Sloughs: If a slough does form, then it is best to withhold active treatment until a line of demarcation between the live and dead tissue has developed. With a sharp scissors the gangrenous tissue should be trimmed away. The open crater of the slough should be packed with iodoform gauze and stimulated every three to four days with silver nitrate ten per cent. Hot packs applied over the area of the slough will also assist in the healing. Should there be much induration about the area, the Ace bandage or the Ace bandage in conjunction with the rubber sponge, the same as used in the active treatment of a varicose ulcer, will add materially to the healing.

(13) End-result of Treatment: The desired end-result of all treatment is a complete organization of the vein and thrombus with a fibrous, cord-like formation where the vein was formerly located. If treatment is thorough and technic perfect, this result will be obtained.

(14) Follow-up Treatment: It is important that each case make repeated visits and be inspected at yearly intervals. This makes certain that no varices have been overlooked and that new varices, which might cause a recurrence, are not permitted to develop.

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